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REVISION OF COAL ESTIMATES FOR WEST SHANSI, CHINA.

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INTRODUCTION.

THE less a region is known, the more does imagination run riot. This is especially true of the natural resources of China. Because the country is large and some of its economic products have been reported from widely separated localities, many persons have jumped to the conclusion that their distribution is universal, and they are referred to as occurring in "immense" and "untold" amounts. Taking an illustration from our own experience, petroleum seepages were reported by Chinese officials and others from scores of localities in Shansi, no less than forty being said to occur in the region of the capital, Taiyuanfu, alone. Notwithstanding, however, careful search by half a dozen geologists and the running down of every report coming to their attention, not a single seepage was found within the limits of the province. Nowhere in the world are circulating rumors more widespread or wilder in their flights of imagination than in China. Referring to petroleum again, but in another part of the country, a deluge of most persistent reports came from localities hundreds of miles apart, but in the end were found to be based on a single occurrence of oil shale in pockets only a few rods in probable extent.

The estimates of the coal resources have a better foundation. Confining ourselves to Shansi, it may be said that coals have been

worked for many centuries at scores of points. Although methods are most primitive, except in the east, near the railroad, the amounts mined have been considerable. As we followed the "Imperial Highway" down the Fen Ho[1] valley southward from Taiyuanfu, several rounded hills overtopping the walls of the cities in their vicinity rose above the flat alluvial plain and proved most puzzling until we found they were built of ashes carried from the cities in the course of centuries. The amount of coal transported along roads and trails on the backs of mules is imposing in appearance, but not really large when judged by modern standards.

The importance of the Shansi coals led to the investigations of Richthofen in 1870 and subsequent years, the results of which appeared in voluminous reports and an atlas a few years later.[2] His field work was confined to the eastern half of the province, although he extended his maps, on the basis of native reports and inferences drawn from conditions in the region personally examined, as far west as the Hwang Ho. Later, special coal districts in eastern Shansi were visited by other geologists, and Willis and Blackwelder made traverses in eastern Shansi which did much to unravel the previously confused details of stratigraphy and structure.[3] Neither Richthofen nor the Willis party, however, penetrated the region west of the Fen Ho, and aside from employees of mining companies or syndicates, who left no published reports, no geologist seems to have entered the region previous to ourselves.

In connection with economic explorations for American clients, some years ago, we and our associates, including V. H. Barnett and E. L. Estabrook, made ten east-west traverses from central Shansi to the Hwang Ho. Although the investigation of coal was not one of the aims of our explorations, the approximate determination of the limits of the coal measures, amongst other formations, was an incidental result. Notwithstanding that the dis-

[1] Also spelled Fön Ho and Fönn Ho.

[2] Richthofen, Baron Ferdinand von, "China" (4 vols.), atlas.

[3] "Researches in China," Publ. of Carnegie Inst. of Wash., 3 vols. and atlas 1907.

tances between the lines of traverse, which averaged 25 to 30 miles apart, were too great to permit complete mapping in a region which, contrary to the assumption of Richthofen, was found to be complexly folded and shattered by block faulting, the sections across the previously unexplored region afforded data which made it apparent that a revision of the estimates of coal resources would be desirable.

In this paper the term "Eastern Shansi field" is used to include the coals lying east of the Fen Ho, while the "Western Shansi field" includes the coals west of the Fen Ho as far as the Hwang Ho, which forms the western boundary of the province. In the eastern field the coals are anthracite; in the west they are bituminous.

STRATIGRAPHY.[4]

Archean and Algonkian.—The earliest formations of west Shansi are the Archean complexes constituting the axes of the north-south mountain ranges. Associated with these, having great unconformities within as well as above and below, are considerable thicknesses of Algonkian gneisses, schists, limestones and slates, all highly folded and metamorphosed.

Man-to Shales.—On the bevelled and locally peneplaned surface of the ancient crystalline and metamorphic rocks was deposited several hundred feet of red Man-to shales. Their age is probably late Lower and early Middle Cambrian. In southwest Shansi they are replaced by heavy quartzites.

Ki-chou Limestone.—This is a hard gray massive limestone, reaching a thickness of 4,000 to 5,000 feet, of Sinian (Cambro-Ordovician) age. It rests conformably upon the Man-to shales or equivalent quartzite where either are present, but a part of the west Shansi area seems to have been above water during the limestone accumulation, for in at least one locality the overlying Shan-si beds appear to lie directly upon the Algonkian.

[4] The Chinese national and provincial names are commonly written in English as single words, but we follow Willis and Blackwelder in their more correct practice of separating the formation names into their component parts. The Chinese Geological Survey appears to follow no consistent plan in the English texts.

Following the Ki-chou accumulation there was a long period of non-deposition, with the land above the sea and subject to erosion during at least the latter part of the time. The land was reduced to a low lying, gently rounded surface, but usually without the removal of any great thickness of limestone. The local absence of the latter, as explained in the preceding paragraph, was probably due to other causes.

Shan-si Formation.—The coal measures of Shansi, indicated on Richthofen's atlas as "productives Carbon" were given the formational name Shan-si by Willis and Blackwelder,[5] which usage we have followed. It is the equivalent of the Yueh-men-kou formation of the China Geological Survey.

The formation ordinarily has a thickness of 300 to 1,000 feet and typically consists of a basal division of alternating sandstones and shales, a middle section of black shales, coals, and some sandstones, and an upper division of sandstones with little shale or coal. The basal sandstone division is often absent as a result of conditions pertaining to the unconformity. Except near the top, there is seldom a trace of the red color which characterizes the overlying formation. Thin limestones occur in the middle section.

The coal measures rest on the eroded Ki-chou surface already described. The erosion plane of the unconformity makes a low angle with the beds, which differ but little in dip above and below the break. The formation merges into the overlying Pu-hsien series by gradual transition.

The age of the coals was considered to be Carboniferous by Richthofen, Willis and Blackwelder, and ourselves, but recently the China Geological Survey, on the basis of paleontological examinations, has referred the lower of the coals ("Tai-yuan formation") to the Lower Carboniferous, and the upper ("restricted Shan-si formation") to the Permo-Carboniferous, with a disconformity between them.[6] There is, however, no marked change in the character of the beds at this horizon.

[5] Researches in China, vol. 1, pt. 1, p. 148.

[6] "Late Paleozoic and Early Mesozoic Sediments of Central Shansi," by E. Norin, Bull. Geol. Surv. China, No. 4, pp. 3–80, Oct., 1922.

Pu-hsien Formation.—The beds immediately overlying the coal measures were originally designated by us as the Fen Ho (Fönho), but the name was abandoned in favor of the present one because of prior use of the first term by Willis and Blackwelder as the designation of a physiographic stage. The formation consists of thick buff sandstones alternating with red shales, which tinge all outcrops with red, having a thickness of 1,000 to 2,000 feet. Although grading into the coal measures at the base, they are, as a whole, distinctly younger. Richthofen classed them as "Uebercarbon" (Permian?); Willis, under the term "Red Beds," designated them as Permo-Mesozoic. The China Geological Survey regards them as "Triassic, lower part probably Permian."

Shen-si Formation.—The Pu-hsien sandstones and shales grade upward without visible break into the hard, often cross-bedded gray sandstones and sandy shales of what we have termed the Shen-si formation. This has a total thickness of 6,000 to 7,000 feet, but probably not more than 1,000 feet are represented in Shansi in the relatively narrow belt lying east of the Hwang Ho between the latitudes 37° 20′ and 36°, having a maximum breadth of about 15 miles and a length of approximately 90 miles. The age of the formation is Jurassic, as determined by the China Geological Survey, apparently from plant remains collected at the coal horizon above the middle of the formation.

Later Formations.—The Shen-si formation is overlain by some thousands of feet of late Jurassic in western Shensi and Kansu, but none occurs in the part of Shansi under discussion, although a basin of Jurassic beds is found near Tatungfu in northeast Shansi and Tertiary beds are reported locally in the west.

GEOLOGICAL HISTORY.

The coal measures and associated formations west of the westermost uplifts of Archean and Algonkian rocks are on the eastern rim of the North Shensi Basin, which extends from the northern Ordos to the east-west crystalline ranges south of Sianfu, Shensi, and from midway between the Fen Ho and Hwang Ho in Shansi to east-central Kansu (Fig. 1).

The downwarping of this region, although it appears to have begun in very early times, was not pronounced until after the deposition of the Ki-chou formation, which is now exposed in the uplands from Kansu to Chihli and Shantung, and points to the presence of a broad open sea up to that time. With the beginning of coal-measure deposition, lagoon conditions were established,

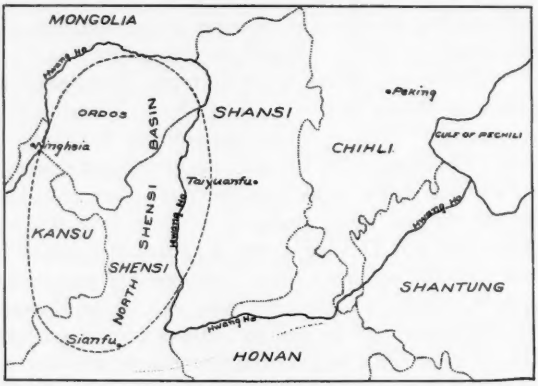

FIG. 1. Sketch map of northeastern China, showing location of the North Shensi Basin.

while following the Permian and extending through the Triassic and Jurassic, embayment or basin conditions prevailed. At that same time the land from which the sediments were derived, including much of Shansi, was subject to a pronounced uplift, accompanied by rather strong folding, faulting and igneous intrusions.

The Jurassic deposition was followed by further uplift, tilting, and a long period of erosion continuing through much of the Cretaceous and possibly into Tertiary time. The rocks of the North Shensi Basin were completely bevelled in places and were elsewhere reduced to an old age topography. In western Shansi the mountains inaugurated in early Mesozoic times were greatly reduced but probably not eliminated. They are now represented by the bevelled crystalline cores flanked by Ki-chou limestone.

On this eroded surface, beginning in late Tertiary times and continuing through the Pleistocene, the great loess mantle, having a thickness of 500 to 1,000 feet or more, was deposited.

The pronounced folding characterizing the edges of the basin as well as the ancient rocks bordering the latter, probably began at the period of Permo-Mesozoic diastrophism, and, after a period of quiescence in Cretaceous and Tertiary times, faulting became active in the early part of the Quaternary period and has continued, with possibly decreasing activity, to the present day. Loess or post-loess disturbances are evident at many points.

One result of the Permo-Mesozoic and Quaternary disturbances was the formation of the great north and south mountain ranges, reaching heights of 8,000 to 10,000 feet in western Shansi. These are faulted masses of ancient crystalline rocks or of Kichou limestone often with an infolding of later beds which may have either anticlinal or synclinal structures.

Between the horsts are grabens,[6a] in which the Shan-si or Puhsien strata often constitute the surface formation. The beds are usually moderately warped, cut by minor faults, and upturned along the major faults which form the boundaries of the blocks. It is these down-thrown troughs which constitute the minor coal basins of Shansi. Occasionally faults occur on only one side of a basin.

EARLY ESTIMATES.

Richthofen's original estimates of available coal in Shansi are well summarized by Bailey Willis.[7] On the basis of an estimated thickness of 40 feet of workable anthracite in all beds throughout an area of 13,500 miles in eastern Shansi, the tonnage of coals in that part of Shansi would be 630 billion tons of 2,000 lbs. each. In west Shansi, the area now under discussion, Richthofen regarded the coal measures as approximately horizontal and essentially continuous throughout the area, and considered the bituminous coal fields as "equally extensive with the anthracite fields of

[6a] While spoken of as grabens, the faulting is sometimes subordinate to the folding, and the basins may be better described as faulted synclines. The basin on Route 9 is a local syncline on the top of the great 'O Shan horst.

[7] "Mineral Resources of China," ECON. GEOL., vol. 3, 19–24, 1908.

eastern Shan-si."[8] According to this assumption the amount of available coal in western Shansi, which includes the region between the Fen Ho and its northern tributaries and the Hwang Ho would be likewise 630 billion tons.[9]

LATER ESTIMATES.

Andrel Kurita, who made an examination of the eastern field in 1896–7, states that it is an unbroken field with coals from 25 to 50 feet in thickness.[10] This would correspond to a thickness not much less than that assumed by Richthofen. The maximum thicknesses presumably represent local thickenings such as reported by the China Geological Survey near Paotehchow, where coals of "36 to 40 feet" and of "20 meters" in thickness were noted.[11]

N. F. Drake, as a result of more detailed studies of the eastern Shansi anthracite field, reduces the estimate of the total thickness of coals from 40 to an average of 22 feet,[12] which would bring down the tonnage from 630 to approximately 350 billion tons. Drake's average probably approximates the truth, notwithstanding the fact that a single coal may sometimes attain a thickness greater than that assigned to the coal beds as a whole. Drake made no estimate of the thickness or tonnage of the coal in west Shansi, but accepting his reduction of the thickness in eastern Shansi and applying it to western Shansi, Richthofen's figure for the latter would similarly be reduced to 350 billion tons.

Willis states[13] that the area of "the coal bearing region" of

[8] Willis, *op. cit.*, p. 24.

[9] Richthofen appears to have used a specific gravity of approximately 1.37 in his computations of anthracite tonnage. This is too low, as the normal gravity of this type of coal usually ranges from 1.5 to 1.8. The specific gravity of bituminous coal, on the other hand, commonly ranges from 1.3 to 1.5. Since Richthofen's value is normal for the west Shansi bituminous coals with which we are dealing, we have used the same figure in the present computations.

[10] "Coal and Iron Deposits in Eastern China," *Eng. and Min. Jour.*, vol. 55, p. 491, 1898.

[11] Wang, C. C., "Stratigraphy of Paotehchow, N. W. Shansi," Bull. Geol. Surv. China, No. 4, pp. 107–118, Oct., 1922.

[12] "Coal Fields Around Tse-Chou, Shan-si," *Trans. A. I. M. E.*, vol. 31, p. 273, 1901.

[13] *Op. cit.*, p. 22.

western Shansi measures 40 miles from east to west and 100 miles from north to south, of which "coal fields occupy one-half" or 2,000 square miles. As he said, however, none had ever traversed it at that time. On the basis of a reduction in area from the 13,500 square miles of Richthofen to the 2,000 square miles of Willis, and a reduction of thickness from the 40 feet of the former to the 22 feet allotted by Drake to the eastern Shensi beds, the total amount of coal in western Shansi would be reduced from 630 billion tons to approximately 51 billion tons.

PRESENT ESTIMATES.

Location and Extent of Coal-Measures.—Our work in Shansi led to the fixing of the limits of the coal bearing measures along ten east-west lines in the previously unexplored area and afforded a more definite basis for calculating coal areas as well as additional data on the probable thickness of the coals. The locations of the lines of traverses and the relations of basin and graben coals are indicated on Fig. 2.

TABLE I.

WIDTH OF AREAS UNDERLAIN BY COAL MEASURES (INCLUDING COALS BOTH IN THE NORTH SHENSI BASIN AND IN GRABENS).

Location of Traverse.	Richthofen's Width (Miles).	Measured Width (Miles).
1. East of Hocheh	—	20
2. East of Paotehchow	—	5
3. Through Shinghsien	105	40
4. West of Taiyuanfu	120	35
5. Through Yungningchow	70	20
6. West of Fenchow	65	35
7. Through Sichow	75	55
8. West of Huntung	70	55
9. West of Taiping	40	25
10. North of mouth of Fen Ho	15	10

The reductions of the previously assigned breadths of the coal-bearing areas resulting from our investigations are summarized in Table I. The principal cities on the routes are indicated for purposes of identification on ordinary maps. The numbers on the map refer to traverses given in the table. The figures include

coal measures assumed to exist under later formations in grabens as well as those outcropping at the surface.

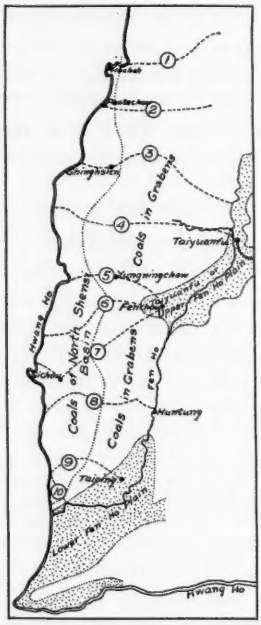

FIG. 2. Map showing routes traversed and relations of basin and graben coals in western Shansi.

It should be said that the coal measure widths ascribed to Richthofen are based on the maps in his atlas, which, however, are incomplete in the north. The west Shansi area was never definitely defined by him, and aside from the position of the Hwang Ho on the west and his designation of the limiting Fen Ho on the east we only have his general estimate of an area equal to that of the eastern Shansi fields for guidance.

To obtain an area of 13,500 square miles between the two

rivers, only 55 miles apart in the south but increasing northward to 110 miles at Taiyuanfu, we must assume a north-south length of Richthofen's coal region of about 170 miles and an average width of 80 miles. This would take in the country from the mouth of the Fen Ho to a point about 20 miles north of Taiyuanfu. As a matter of fact the coal measures under consideration extend further north than Paotehchow, a distance of more than 250 miles from the mouth of the Fen Ho.

TABLE II.

ANALYSES OF ROUTES ACROSS COAL REGION OF WESTERN SHANSI SHOWING WIDTH IN MILES OF COAL-BEARING FORMATIONS AND INTERVENING AREAS.

Route.	West Belt.	Interval.	1st Basin.	Interval.	2d Basin.	Interval.	3d Basin.	Interval to Fen Ho Valley.
1.....	10	5	10					50
2.....	5							60
3.....	25	35	15					30
4.....	5	10	10	70	10	2	10	2
5.....	15	10	5					40
6.....	25	18	¼	11	10			0
7.....	40	20	15					
8.....	45	4	8	3	1	2	1	6
9.....	20	5	5	10				
10.....	10							5

In Table II., the occurrence of the coal measures is analyzed, proceeding from west to east as in Table I. Route numbers are the same in both tables. The column headed "West belt" refers to marginal coal formations of the east rim of the North Shensi Basin. They dip downward under later formations toward the west. The remaining area is a complex of folds and fault-blocks, with basins of the graben type separated by horsts of Cambro-Ordovician limestone, and crystalline rocks of Algonkian or Archean age. The mileages in the last column are those extending from the east margins of the easternmost graben to the edge of the alluvium in the Fen Ho valley, the eastern limit of the western Shensi coal bearing area of Richthofen and Willis, or its northward continuation.

It will be noted that the western belt, on the rim of the Shensi

Basin, varies from 5 to 45 miles in width, and that the local exterior basins range from a fraction of one to 15 miles in breadth. The north-south extent of the minor coal basins cannot be estimated with accuracy because of the severe faulting in the 25-mile intervals between traverses. Even basins at apparently corresponding points on adjoining traverses are likely to be different in reality. Some of the basins are probably 50 and may be 100 miles in length, while others are almost certainly only a very few miles long.

Depth of Coal Measures.—The coal measures on the east rim of the Shensi Basin, east of the Hwang Ho, dip westward at varying angles, usually averaging under 3°, the general slopes being interrupted and modified by normal faulting. On Sections 1, 2, 9 and 10 the coal measures are at the surface at the Hwang Ho. On Sections 3 and 4 they are probably 2,000 feet below the river; on Section 5 not much over 500 feet; on Sections 6 and 7, 1,500 to 2,000 feet; and on Section 8, 1,500 feet. In most of the grabens the coal measures lie at the surface, but on Sections 3 and 5 they are overlain by red Pu-hsien beds of no great thickness. It is to be noted that the depths are to the top of the coal measures or Shan-si formation, and that the coals themselves are likely to be from 300 to 500 feet deeper.

Thickness of Coal.—No complete sections of the coal measures of west Shansi have been determined, except in the Paotehchow and Taiyuanfu districts.[14] There are ordinarily about a dozen seams, most of which are only a foot or two in thickness. Usually, however, two or three of the beds will have thicknesses of 5 or 6 feet, one or more of which may thicken locally, as near Taiyuanfu, where an 18-foot bed is extensively mined, and near Paotehchow where a bed from 36 to 67 feet (20 meters) is reported. The mines are on a smaller scale than in east Shansi and much less coal is being transported on the trails, but this is likely to be due to the fact that the cities are fewer in number and usually smaller in size than those of the Fen Ho plains and in eastern Shansi. On the whole it is believed that the thickness in western

[14] Wang, C. C., *loc. cit.*; Norin, E., *loc. cit.*

Shansi will be little less than in the eastern part of the province. For the purposes of the present estimates the thickness of workable coals in west Shansi is taken as 20 feet. The thickest coals usually occur in the upper or Permian division.

Area of Coal Measures.—Connecting the outcrops crossed on the different traverses where possible, and fixing their limits as near as may be when this cannot be done, we arrive at the figure of 17,500 square miles as the probable area within which coals may occur in western Shansi. In reaching this result we have included an area extending from north of Paotehchow to the mouth of the Fen Ho, a distance of 250 miles, and from the Fen Ho to the Hwang Ho, an average distance of 70 miles. The coal area about Ta-tung-fu, which is a small separate basin of later age, is not included. The total coal-bearing area as measured by us is some 4,000 square miles in excess of that assumed by Richthofen, and 13,500 square miles in excess of that postulated by Willis.

Richthofen assumed the entire coal bearing area of 13,500 square miles in western Shansi to be actually underlain by coals, while Willis believed that only half, or 2,000 square miles, of even the restricted area regarded by him as containing coal measures would be productive. Our measurements indicate that approximately 9,000 of the 17,500 square miles of coal-bearing area actually contain coal measures. Of this area, 5,600 square miles lie on the west flank of the Shansi mountains along the rim of the North Shensi Basin, while 3,400 square miles occur in basins of graben character. The estimate of area is probably very nearly correct for the Shensi Basin, but will be subject to revision in the case of the local grabens when their limits are completely worked out on the ground.

Existing Tonnage.—For the purpose of the present estimates it is assumed that the entire coal-measure territory is coal bearing. On the basis of an area of 9,000 square miles of coal measures, carrying coals having an average aggregate thickness of 20 feet, we reach an estimate of approximately 210 billion tons as the existing supply in west Shansi, of which 128 billion tons are in the North Shensi Basin and 82 billion tons in the graben "basins."

Richthofen's estimate of an area of 13,500 square miles and a thickness of 40 feet would correspond, as elsewhere stated, to 630 billion tons. The same area, extending Drake's east Shansi estimate of 22 feet of coal to west Shansi, would give 350 billion tons, or, using our area of 9,000 square miles, a volume of 233 billion tons. Willis' estimated area of 2,000 square miles would afford 51 billion tons on the basis of a 22 foot thickness of coal and 47 on the 20-foot basis used by us.

There is a certain likelihood of error in our estimates owing to our lack of knowledge of the territory between traverses, of the actual average thickness of the coals, and the percentage of the coal measure areas, probably not more than 10 or 15 per cent., in which coals are absent, but the figures approximate the true tonnage more nearly than was possible before the region was visited.

Amount of Coal Recoverable.—Practically all of the coals of the Shansi series would be recoverable by modern methods if their thickness warranted. They outcrop frequently in the valleys which everywhere cut the uplands of western Shansi and could be worked by drifts from the surface. Nowhere are the beds much if any over 2,000 feet below the valleys. The rainfall is light and water difficulties should not be serious, in fact, many of the mines on the outcrops could be so located as to be self-draining.

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SOME NOTES ON THE GEOLOGY OF THE JEROME DISTRICT, ARIZONA.

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THE purpose of this paper is to summarize the results of recent geological work in the Jerome district of central Arizona, avoiding, in so far as is possible, repetition of facts that have already been established. Since the valuable paper by L. E. Reber, Jr.,[1] enough new facts of importance have been brought out to warrant their being recorded in the literature.

GEOLOGICAL COLUMN.

There are several changes to be made in the geological column. One of these is of importance with regard to fixing the age of the primary mineralization and of the secondary enrichment of the district. Others are of value only in being corrections. The following table shows Reber's separation of the formations, as set forth in 1920, together with the proposed new system:

TABLE I.

	Reber.	Proposed.
QUATERNARY	Recent gravels	Recent gravels
	Verde lake beds	Verde lake beds
		Basalt flows
TERTIARY	Pliocene basalt flows	Pliocene basalt flows
	Pre-basalt conglomerate	Pre-basalt conglomerate
PERMIAN	Supai sandstone	Supai sandstone
MISSISSIPPIAN	Redwall limestone	Redwall limestone
DEVONIAN	Temple Butte limestone	Temple Butte limestone
		Basal red sandstone
CAMBRIAN	Tapeats sandstone	

[1] L. E. Reber, Jr., "Geology and Ore Deposits of the Jerome District," *Transactions A. I. M. E.*, 1920.

TABLE I.—*Continued.*

PRE-CAMBRIAN	Mineralization	Mineralization
	Andesite dikes	Andesite dikes
	Mineralization	Mineralization
	United Verde diorite	United Verde diorite
	Cleopatra quartz porphyry	Cleopatra quartz porphyry
		Deception quartz porphyry
	Bedded sedimentaries	Bedded sedimentaries
	Greenstone complex	Greenstone complex

Changes.—Across the Verde Valley from Jerome, in the foothills of the Mogollon escarpment, P. C. Benedict noticed limestones of the Verde lake beds formation (Quaternary) interbedded with flows of basalt. This means that some of the basalt near Jerome is Quaternary. Both Tertiary and Quaternary basalts are known to exist in the San Franciscan volcanic field in the vicinity of Flagstaff, 50 miles north of Jerome. It is not impossible that some of the lake beds are of Tertiary age: their base has never been penetrated even in the deep well-borings which furnish the only information concerning the lower members. A great thickness of limestones shows that a long time elapsed between the outpouring of the Tertiary flows that dammed the Verde River and the later flows which are interbedded with the Quaternary sediments.

Until now, the basal red sandstone has been grouped with the Tapeats [2] of the Grand Canyon section, which is Upper Cambrian. Lausen and Wilson, of the Arizona Bureau of Mines, recently published a bulletin [3] in which they showed that in the Payson district, about 60 miles southeast of Jerome, the basal sandstone is of Upper Devonian age. Bony plates of fresh-water fishes were identified by Dr. Stoyanow. So far as I am aware, no fossils have been found in the sandstone at Jerome. But the two sandstones are identical in appearance and overlie the same formations. Moreover, there is no apparent unconformity between the basal sandstone at Jerome and the Temple Butte (Upper Devonian) limestone. It seems logical, therefore, to classify the

[2] *Op. cit.*, page 5.

[3] Carl Lausen and E. D. Wilson, "Gold and Copper Deposits near Payson, Ariz.," Bull. 120, Ariz. Bur. Mines, 1925.

sandstone as Upper Devonian until it can be proven to be of a different period. The importance of knowing the age of the basal sandstone can be appreciated when we consider that its interpretation as belonging with the Cambrian, together with the fact that it overlies the gossan of the United Verde Extension orebodies, has been the *sine qua non* of all previous writers, except W. Tovote, in proving the older rocks, the primary mineralization, and the secondary enrichment of the Extension mine to be pre-Cambrian. Tovote[4] did not doubt the accepted view of the age of the sandstone. Now, correlation furnishes the only basis for the belief that the older rocks and, hence, the primary sulfides are pre-Cambrian. And it is doubtful if there is any justification for holding the view that the peneplanation and the enrichment of the ores are exclusively of pre-Cambrian age.

Reber groups together as "greenstone" all formations older than the Cleopatra quartz porphyry except the bedded sedimentaries. Recent work has made it seem desirable to place the Deception quartz porphyry, which is thus included with the greenstones, by itself.

The greenstone series is intruded by two sills of quartz porphyry. The older of these was first pointed out by J. R. Finlay,[5] who named it Deception porphyry after the gulch in which its best surface exposures are found. The younger and uppermost is called Cleopatra quartz porphyry. Proof as to the relative ages of these two formations has been obtained by a study of their contacts. As has been pointed out before,[6] when the two rocks are in contact with each other, the older Deception porphyry usually gets coarser grained while the Cleopatra porphyry gets finer. In connection with work on the Verde Central mine, P. C. Benedict studied the two quartz porphyries in some detail under the microscope. He found that the Deception porphyry[7]

[4] W. Tovote, "Notes on the Jerome District," Bull. 142, A. I. M. E., Oct., 1918.

[5] J. R. Finlay, "The Jerome District of Arizona," *Eng. and Min. Jnl.*, vol. 106, Sept. 28 and Oct. 5, 1918.

[6] J. L. Fearing, Jr., and P. C. Benedict, "Geology of the Verde Central Mine," *Eng. and Min. Jnl.-P.*, vol. 119, p. 609.

[7] P. C. Benedict, unpublished Master's Thesis (M. I. T.).

is a true quartz porphyry, probably intrusive, and not a fragmental. This is opposed to Reber's view,[8] which is expressed as follows: "In Deception Gulch, . . . the nature of the material is open to question. The appearance is similar to that of known volcanic fragmentals and locally there are some obscure indications of its fragmental character. The microscopic evidence is conflicting but seems to point in the same direction." As described by Benedict, the rock is now composed of original quartz phenocrysts and secondary quartz, sericite, and chlorite. Originally it contained abundant but rather small euhedral quartz phenocrysts and some feldspar phenocrysts in a fine-grained groundmass. The quartz phenocrysts are considerably corroded and embayed by secondary fine-grained quartz. Sericite veinlets also cut them along tiny cracks produced by dynamometamorphism. They are frequently surrounded by secondary quartz usually separated by lines of inclusions. The original feldspars are entirely replaced by sericite. In outward appearance, in chemical composition, and under the microscope the two quartz porphyries present no striking differences. Their field separation depends chiefly upon the larger size and greater abundance of the quartz phenocrysts in the Cleopatra porphyry. The best exposures of the Deception porphyry are in the underground workings of the United Verde Extension mine where two crosscuts have penetrated thicknesses of from 2,000 to 3,000 feet (measured perpendicular to the dip). Nowhere is there any trace of fragmental material. It seems doubtful that the Deception porphyry could even have been extrusive, for there is no vesicular or amygdaloidal texture, no flow structure, and no parallel orientation of phenocrysts.

The Deception porphyry is not to be grouped with the greenstones because not only is it not a "greenstone," but it is related in age to the Cleopatra porphyry, which it so closely resembles. It has by no means been subjected to as much metomorphism as the older rocks. Benedict says that on the whole, the Cleopatra porphyry shows a little less extreme alteration than the Deception

[8] L. E. Reber, Jr., *op. cit.*, p. 10.

porphyry. But the two formations cannot be grouped together because the former is related to the mineralization of the district, as will be discussed later, while no importance attaches to the latter except as a possible favorable depository for ore solutions.

The Greenstones.—The so-called "greenstone complex" includes a very thick series of volcanic flows and fragmentals with some less extensive layers of interbedded sandstone, shale, or limestone. It is only within the last two years, upon the suggestion of F. Searls, Jr., that any real effort has been made to differentiate the various members of these old formations. In proposing this separation, Searls wanted to find out which of the greenstones were more favorable for ore deposits as well as the structural conditions localizing ore. Although no new ore has been found as a result of this work, it has been most useful in restricting prospecting to favorable areas and interesting in clearing up many questions concerning ore deposition in the district. The work of Messrs. Searls and Hansen at the United Verde mine and of the writer at the United Verde Extension mine has shown that the two orebodies are localized in the crest and in the trough, respectively, of anticlinal and synclinal folds in the greenstones, which have been tilted to a nearly vertical position. And it seems likely that the extra brecciation which naturally comes at these places has been of much importance in providing the right conditions for ore deposition.

After one is familiar with the characteristics of the various greenstone formations, they are not difficult to map accurately except at the top of the pre-Cambrian peneplain where long-continued weathering has obliterated any trace of original texture or structure. But so thorough has been the pre-Cambrian metamorphism in altering the original minerals making up the rocks that the microscope is often utterly helpless in determining their original composition. In correlating them, field relationships are a more reliable guide. Of course, the main idea in separating the greenstones has been to work out the structure, and it does not matter whether a certain rock is rhyolite or latite. The important consideration is whether it is favorable or unfavorable

for mineralization. Roughly classified, the following section, from youngest to oldest, has been mapped in the workings of the United Verde Extension mine:

Basic tuff	Not fully exposed.
Diabase flow or sill, often of diorite texture	± 1200 feet.
Andesitic or dacitic tuff	0 to 200 feet.
Rhyolite tuff	± 600 feet.
Bedded shale or ash	0 to 70 feet.
Basic tuff	Not fully exposed.

The underground relationship of these formations is shown in Fig. 1.

Thin sections of the diabase, studied collectively, show that it is intrusive and has a distinctly diabasic habit. The primary minerals are medium plagioclase and pyroxene with occasional quartz and magnetite as accessories. The secondary products include chlorite, epidote, carbonates, leucoxene, etc. In spite of the microscopic evidence, it is doubtful whether the rock is intrusive or extrusive. Structurally, it seems to be a flow, and I have classified it as such. It has abundant elongate amygdules at its upper surface and lacks inclusions of the overlying basic fragmental or persistent offshoots into it. If it is a flow, it is thick enough so that its inner portions might well resemble an intrusive.

The rhyolite tuff is an igneous fragmental rock of porphyritic, vesicular, or amygdaloidal texture and frequently glassy. The primary minerals are quartz, feldspar in traces, and a ferromagnesian mineral which has been completely destroyed. As accessories there are magnetite and apatite. Alteration products include sericite, chlorite, quartz, carbonate, epidote, and leucoxene.

The bedded sedimentaries, where least altered, are very silicious and probably represent a fine-grained sandstone or a sandy shale. The original bedding can usually be seen with the unaided eye.

The Black Schist.—In the vicinity of mineralized ground, the rocks are frequently observed to be altered to a black schist almost entirely composed of ferruginous chlorite. In the United Verde Extension mine, both of the quartz porphyries, the rhyolite tuff, and the bedded sedimentaries have been observed grading

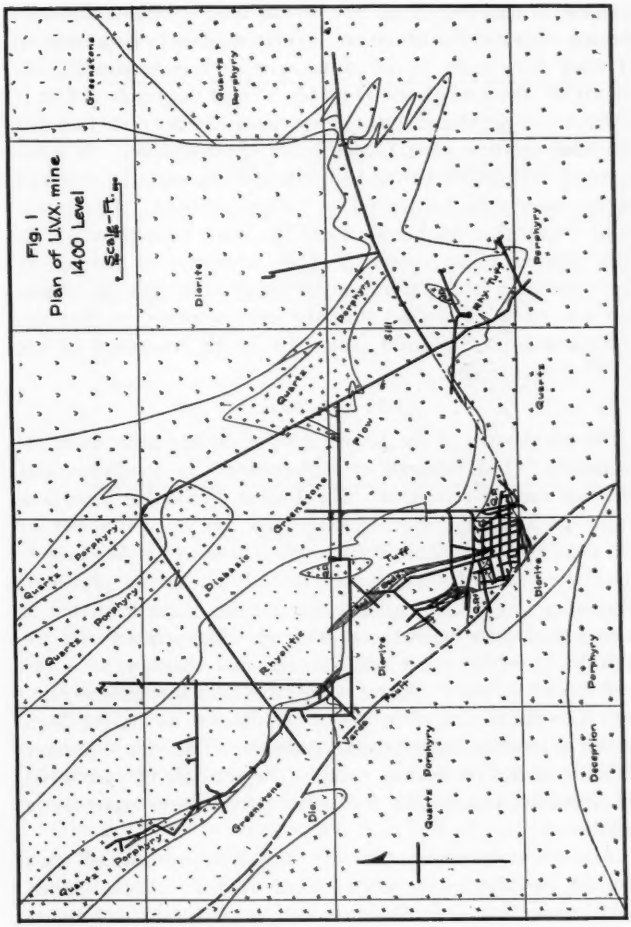

FIG. 1. Plan of United Verde Extension Mine, 1400 level.

into black schist. Gradations from quartz porphyry into black schist show that the quartz phenocrysts tend to be retained until the last stages of the alteration. There appears to be a removal of silica from some of the phenocrysts with corresponding additions to others which act as nuclei; so that the result at first is fewer but larger phenocrysts. Experience has demonstrated that this black schist is most favorable for ore deposition. It is believed to have resulted from hydrothermal alteration by solutions slightly older than, but related to, the ore solutions. The microscope shows that sulphides replace the black chlorite which, in turn, replaces older material.[9] The occurrence of patches of black schist far from mineralization means either that this alteration was more widespread than the mineralization, or that dynamometamorphism played some part in the formation of the schist, at least locally.

ORE DEPOSITS.

The ore deposits of the Jerome district are lenticular schist replacements. The evidence of replacement[10] is conclusive and does not require repetition. The United Verde ore zone is a steeply pitching pipe approximately 500 feet by 1,100 feet in plan except in the bottom levels where it is narrower but longer. The United Verde Extension main orebody is a vertical pipe with dimensions of 300 feet by 600 feet on the 1,400 level, but it pinches somewhere below the 1,600 level. The primary ores are sulphides in which pyrite predominates and chalcopyrite is the chief copper mineral. Quartz is the most abundant gangue mineral. Genetically, the ores are to be classed as having been formed at intermediate depth and pressure. They are intimately related to bodies of igneous rocks. The presence of specularite and magnetite means that formation temperatures were above normal.

Localization of Ores.—The ore deposits were formed soon after the intrusion of the United Verde diorite. At the United Verde mine, they occur under an arch in the impervious diorite

[9] L. E. Reber, Jr., *op. cit.*, p. 14.
[10] *Op. cit.*, p. 11.

hanging-wall, where ascending solutions of magmatic origin would naturally be localized. In as much as the Copper Chief orebody, in the Southern end of the district, has no connection

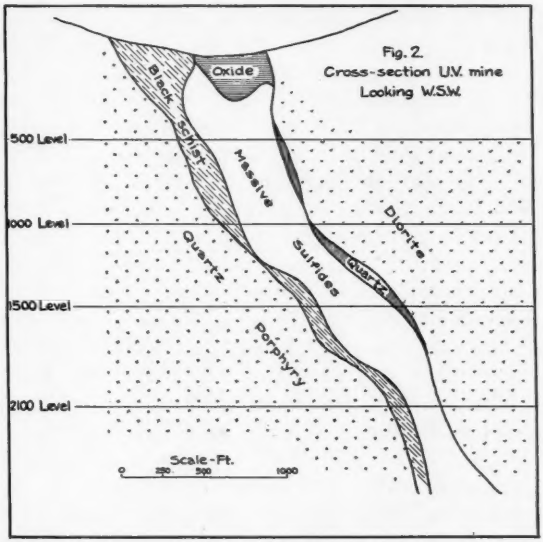

FIG. 2. Cross-section, United Verde Mine, looking west-southwest.

with any diorite, and, further, that the diorite barely touches the tip end of the United Verde Extension orebody and is practically vertical and not arch-shaped, this structure can not be held as a prerequisite for ore deposition. But, nevertheless, there is no denying that it has been of great importance in determining the intensity of mineralization and large size of the mineralized area at the United Verde mine. The factors that are believed to have controlled ore deposition and to be prerequisite for finding important orebodies elsewhere in the district may be summarized as follows:

1. Proximity to upper contacts of the Cleopatra quartz por-

phyry sill at places where favorable structures exist and where the rock itself is schistose.

2. Easily replaceable, schistose greenstones in contact with the favorable porphyry areas, and favorable structures in the greenstones with the attendant development of extensive brecciation.

An interesting anomaly is arrived at from a structural study of ore occurrence in the Jerome district in as much as the ore, though later than the diorite, is clearly related to the Cleopatra quartz porphyry, an older rock. The ores, the diorite, and the porphyry undoubtedly came from the same magma reservoir. The diorite, however, being relatively impervious, is massive and quite fresh even within a few feet of mineralization, while portions of the Cleopatra porphyry are very schistose and pervious. It does not require much stretching of the imagination to arrive at the conclusion that the natural thing to happen in a case of this kind is for the ore solutions to come up through schistose portions of the porphyry, choosing the path of least resistance. That this is actually what has taken place is proven by facts. The schistose areas of porphyry often contain disseminated sulphides, the clue to the fact that they were paths for mineralizing solutions. In one instance at the United Verde mine, and in several at the Extension, secondary enrichment has made low-grade ore of these slightly mineralized porphyry zones. The greatest concentrations of ore are found where the schistose porphyry has outward bulges or flattenings of the dip at its upper surface. But perhaps the most convincing argument in support of the idea that the Cleopatra porphyry is the rock most closely related structurally to the mineralization is the fact that, throughout the district, a certain amount of sulphide is generally found along its margins. Then too, the Copper Chief and Verde Central ores occur at some distance from any diorite. Commercial ore has resulted when rocks favorable to replacement have adjoined favorable porphyry areas. Granting the importance of the Cleopatra quartz porphyry in localizing ore, it follows, since the ore solutions came from below, that the upper contact is the most favorable place at which to look for important concentrations of ore. And it should be

mentioned here that the two big mines of the district are found at this upper contact.

Microscopic and field evidence leads to the belief that the rocks most susceptible to replacement, in addition to the porphyry itself, are the bedded sedimentaries and adjacent acid volcanic fragmentals. A schistose and crushed condition seems to be the most important prerequisite, for the extreme permeability, which apparently is necessary, is thereby supplied. The basic volcanic greenstones seem to afford a wholly unfavorable environment. The difference in the replaceability of the various rocks is believed to be due not so much to their unlike chemical natures as to the fact that the acidic rocks crack and are brecciated the more easily. When the bedded greenstones make ore, the original bedding laminations are nearly always preserved even when replacement is practically complete. By it one is able to trace preore folds.

Paragenesis.—In addition to pyrite, quartz, and chalcopyrite, lesser amounts of the following minerals have been identified at Jerome: sphalerite, galena, bornite, specularite, magnetite, tennantite, arsenopyrite, and carbonates. Reber states[11] that "the pyrite, chalcopyrite, and sphalerite are intergrown in such a fashion as to indicate their essentially contemporaneous development. These earlier sulphides and quartz, however, are in many places full of tiny cracks filled with chalcopyrite of a later phase of the mineralization. Evidence of any replacement of the earlier sulphides by the later has not been found." It was pointed out by Benedict[12] that most of the chalcopyrite was introduced after the main pyrite epoch had been brecciated. The widespread brecciation of the early pyritic phase he attributes to the intrusion of the andesite dikes. If the microscopic evidence has been interpreted correctly and there has been no replacement of pyrite by the second generation chalcopyrite, it is not likely that there has been any shattering by replacement, as has been discussed by Wandke[13] in connection with certain other deposits, and it is

[11] L. E. Reber, Jr., *op. cit.*, p. 11.

[12] P. C. Benedict, *op. cit.*

[13] A. Wandke, ECON. GEOL., vol. XX., No. 6, p. 605.

more than likely that Benedict is correct in his interpretation of events. There is no lack of evidence underground in support of the idea that important chalcopyrite came in later than the dikes. An instance was noted by F. G. Wells, late of the United Verde geological department, in which one of the dikes, diverted from its normal course, had made a rude relatively impervious dome. This dome served as a trap for the later ore solutions which deposited chiefly chalcopyrite.

Secondary Enrichment.—At the United Verde Extension, secondary enrichment has made practically the whole sulphide pipe commercial. The ore consists principally of chalcocite and pyrite. In 1924, the average grade of ore mined was above 12 per cent. in copper. The chalcocite has replaced chalcopyrite and has also been deposited along cracks in the pyrite. It is doubtful if there has been much, if any, replacement of pyrite by chalcocite, since, even in the upper levels where enrichment has been the most pronounced, chalcocite is found almost entirely in minute cracks and the inter-crack areas are fresh massive pyrite.

One further point of interest deserves to be mentioned. It is the view of some geologists that secondary enrichment stops at the water-level. But the evidence offered by a study of the Extension occurrence leads to the conclusion that when enrichment takes place under ideal conditions, chalcocite deposition starts at the water-level. By ideal conditions is meant a region in which elevation has not proceded any faster than erosion and enrichment, and in which subsidence has not resulted in a rising water-level. The Extension orebody is uniform and there is no reason to suspect that the water-level in any one part of it should have been higher or lower than in any other part at the same time, except locally. The bottom of the oxide zone, or top of the enriched zone, furthermore, is as abrupt and as flat as could be desired for a textbook illustration. Now, if secondary enrichment stops at the water-level, to what can we ascribe the flat plane at which it starts in the United Verde Extension? Under the ideal conditions which have been outlined above, it seems obvious that oxidation should prevail down to the water-table, and reduction

below it. The United Verde once must have had an enriched zone as extensive as that of the United Verde Extension. Numerous pieces of "float," found along the hillside from the mine workings to the Verde Valley, point to such a probability. There is no evidence that would preclude its having existed. Whatever

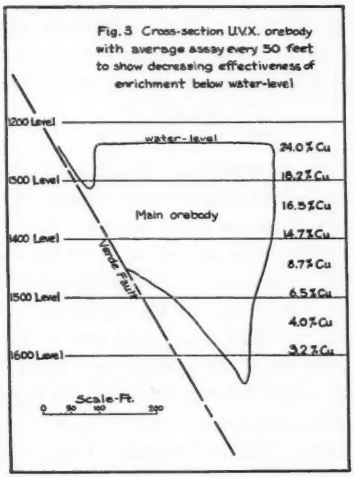

FIG. 3. Cross-section, United Verde Extension, orebody, with average assay every 50 feet to show decreasing effectiveness of enrichment below water-level.

there was has been almost entirely wasted away by the post-Tertiary erosion. The chalcocite zone of the Extension has been protected at least since Devonian time by its mantle of Palæozoic sediments.

Age of the Ore.—Granting the pre-Cambrian age of the older greenstones and related intrusives, it follows that the age of the ore is also pre-Cambrian. At the time Jaggar and Palache mapped the Bradshaw Mountains Quadrangle for the United States Geological Survey years ago, they included in the pre-Cambrian system a granodiorite which is now believed by Lind-

gren to be of Mesozoic age and similar to granodiorites of the Sierra Nevada. This rock is closely related to certain ore deposits of the Bradshaw Quadrangle, but is not believed to outcrop within 20 miles of Jerome and does not appear in any mine workings in the district. The fact that it has no bearing on ore deposition in the Jerome district is evident from the lack of mineralization in the Palæozoic rocks. Unless the basal sandstone can be shown to be of Cambrian age, the age of the chalcocite enrichment of the United Verde Extension can not be proven to be pre-Cambrian.

THE VERDE FAULT.

The most prominent structural feature of the Jerome district is the Verde fault, which strikes northwesterly in the vicinity of the mines and dips northeast at 60 degrees. It is a normal fault with a shift along the strike as well as along the dip. The vertical and horizontal components are 1,700 feet and 1,500 feet, respectively.[14] The formations on the northeast, or hanging-wall side, have moved relatively downward and to the south. The result of the weathering of the fault-scarp is that in the foot-wall, the pre-Cambrian rocks outcrop, while in the hanging-wall they are overlaid by 800 feet of later rocks.

Relation of Verde Fault to Extension Ore.—The relationship of the Verde fault to the United Verde Extension main orebody has always been more or less of a puzzle to many geologists and engineers visiting the mine. A conclusion to which they frequently revert is that the ore is localized by the fault zone and will follow the fault downward indefinitely. The argument offered is that even though there is admittedly post-ore faulting, there may also have been movement along the same break in pre-Cambrian times before ore deposition. And even if there is no pre-ore movement, a line of weakness might have existed up which the ore solutions came and near which they acted most effectively.

Fig. 5, which is a vertical section through the center of the Extension main orebody at right angles to the strike of the fault,

[14] The horizontal displacement was determined by Mr. Searls.

shows the structural relationship. The orebody, as drawn, is observed to pinch out slightly below the 1,600 level. It actually does so in this section. The main primary sulphide stem, however, extends at least two or three hundred feet below the 1,700

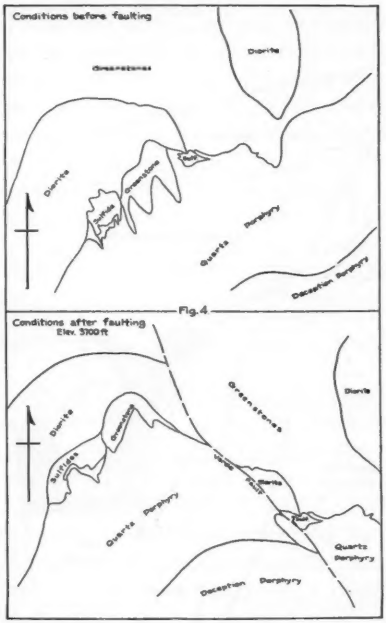

FIG. 4. The Verde Fault.

level, where it is then cut off by the fault. It is separated from the main orebody by another fault, called the Hanging-wall fault, the movement along which has left it higher and farther north. Near the main orebody, the Hanging-wall fault joins the Verde fault. As shown in the section, the main orebody is not affected by it and is not in any fault zone. That the Hanging-wall fault does not cut the main orebody is proven by the fact that there is

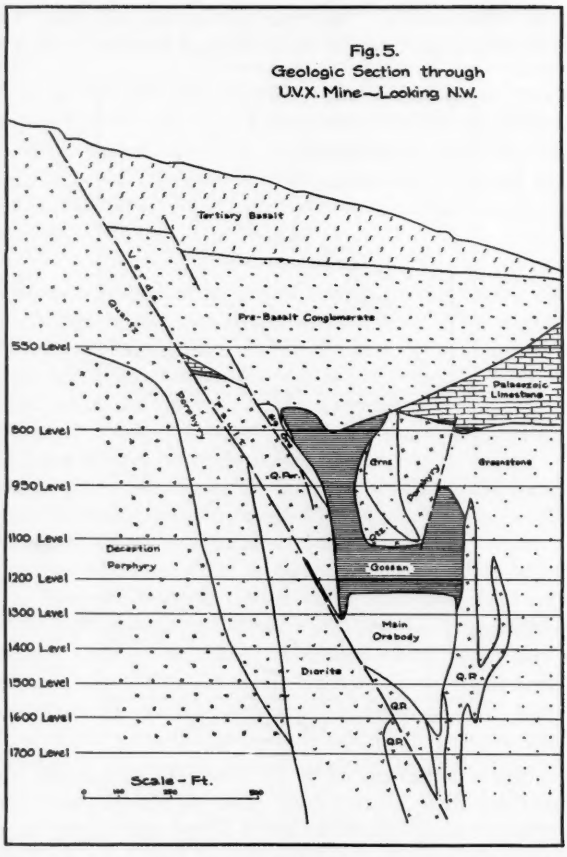

FIG. 5. Geologic section through United Verde Extension Mine, looking northwest.

no displacement of the margins of the ore. It seems much more reasonable to assume, therefore, that the Extension orebody, with its kaolinized and greatly softened surrounding rocks, made a line of weakness for the subsequent faulting, rather than that the ore solutions were guided by a pre-existing fault or line of weakness. Moreover, if all that is required for ore deposition in the Jerome district is a fault zone, the extensive work which has been done along the Verde fault for several miles ought to have given some encouragement for ore. And there are other similar faults in the district that also show no signs of mineralization. Both the United Verde and United Verde Extension orebodies are localized in the manner described in the preceding pages. In mode of occurrence they are practically identical. Furthermore, the United Verde pipe, which is much the larger, is definitely not in or near any fault zone. What, then, is the justification for trying to explain the Extension occurrence by the Verde fault?

PROSPECTING.

Prospecting in the Jerome district has always proved to be expensive and is not warranted when there are no favorable gossans at the surface unless the conditions meet the requirements for ore. All prospecting east of the Verde fault, where the ore horizons are under cover, is necessarily blind until the pre-Cambrian formations are reached and must then be guided by the rocks encountered. The prerequisites for ore deposition are so complicated and specialized that it seems doubtful if they can be duplicated elsewhere in the district, except possibly where the pre-Cambrian rocks are covered and no previous work has been done.

ACKNOWLEDGMENTS.

In closing, the author wishes to acknowledge the kindness of Mr. George Kingdon, General Manager of the United Verde Extension Mining Company, for permission to publish this article and the mine maps.

EDWARDS, N. Y.

A SALT DOME "SOLENAYA SOPCA" IN NORTHERN SIBERIA.

I. P. TOLMACHOFF.

In 1905 the writer, at that time the leader of the Khatanga expedition commissioned by the Russian Geographical Society for investigation of the rivers Khatanga and Anabar, had an opportunity to visit a rock salt locality in one of the most isolated parts of northern Siberia. Solenaya Sopca (the literal translation of this Russian name would be "A Salt Dome"), where salt outcrops, has been known by name since the seventeenth century, and specimens of salt from here have found their way by natives and traders into Russian museums; but until the date referred to, the locality had never been visited by any scientist, and its position was given on maps only very vaguely.

The writer visited Solenaya Sopca under unfavorable conditions; at latitude 74°, winter was just starting, the country was covered with snow, and the days were short. Because of this, not more than one hour was spent on the investigation of this interesting locality. Moreover, at that time the problems connected with salt domes had not, of course, been so well worked out as during the last ten to twenty years, and the observations of the expedition were certainly not on the level of present requirements.

Solenaya Sopca is located in the northern part of the triangular peninsula separating Khatanga and Anabar Bays, near the northern point of a small peninsula, Yurungtumus, protruding northwards from the main peninsula and bordering Nordvik Bay on the west. With the exception of some small relief produced by a number of rivulets, the surface of the Yurungtumus Peninsula, as well as that of Cape Paksa (Nordvik) (the latter borders Nordvik Bay on the east), is flat, although not low, the cliffs of Cape Paksa as well as of Cape Preobrajenie being over 70 feet

high. On this plain Solenaya Sopca protrudes over 300 feet above the surface in the form of a conical, nearly symmetrical, dome, with moderately steep slopes, a mile or a mile and a half in diameter.[1] Arctic Pilot[2] calls it "a conspicuous hill, 390 feet

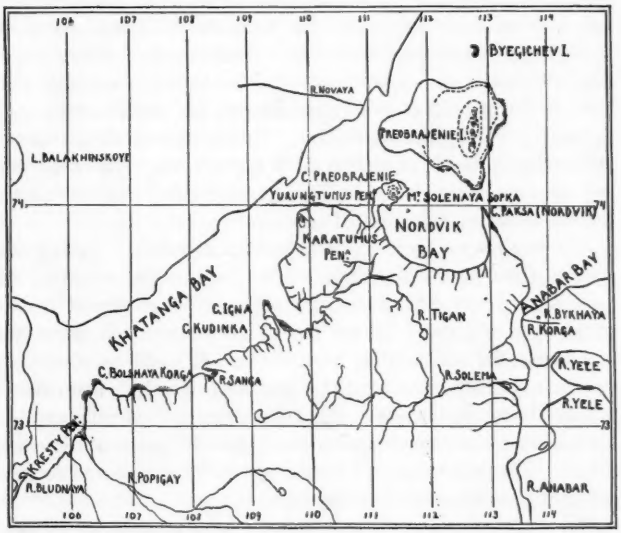

FIG. 1. Map of northern Siberia between Khatanga and Anabar bays giving the location of the salt dome Solenaya Sopca. After the Russian Admiralty map No. 986 (1923) revised and corrected by the writer. Scale, 1 in. to 40 nautical miles, or 1 : 2,918,400.

high," as it is well seen from the sea, but it is not less conspicuous from the mainland.

It was impossible, all conditions being considered, to get an adequate idea of the geological composition of Solenaya Sopca.

[1] Solenaya Sopca had not been surveyed, but only sketched and no detailed description was made at the time, nor was it well represented photographically. Therefore the above description is rather a general recollected impression of the hill.

[2] Third edition, 1918, p. 514.

The slopes of it were, probably, mostly covered with a drift material. Outcrops of rock salt were found near the top of the hill, covered with a layer of cap rock, about fifteen feet thick, composed of gravel and sand firmly frozen, and of recent origin. The salt itself was crystalline sodium chloride, chemically very pure, and was used as salt by the natives (of course, rather as a curiosity) and by the expedition. Owing to a small amount of enclosed clay it had a rather dirty appearance. No other salts nor gypsum were found.[4] The investigation was, of course, limited to the examination of outcrops.

The coasts of Nordvik Bay are composed of very little disturbed, nearly horizontal marine strata of Neocomian age, as is shown by a few fossils, particularly cephalopods,[3] collected here.

The locality appeared to be a geological puzzle. Taking into account the theories prevailing at that time on the origin of salt rock, it was very difficult to imagine how this particular deposit could have originated on the top of an isolated hill about 300 feet above the surrounding area. The hill could be considered only as a remnant of wider distributed deposits which had covered at least the whole surface of the Yurungtumus Peninsula and had been everywhere removed with the single exception of Solenaya Sopca. The salt examined by the writer thus appeared to be a remnant of a larger preëxistent layer.

The removal referred to could have been effected by erosion, Solenaya Sopca representing in this case a "butte," as such isolated masses are known in the western regions of Northern America.[5] As mentioned above, the geology of Solenaya Sopca has remained unknown, but supposing it were a "butte," it could be composed of Cretaceous, Tertiary, and Post-Tertiary sediments. The latter was really found on the very top of the

[3] Pavlow, A., "Les Céphalopodes du Jura et du Crétacé inférieur de la Sibérie septentrionale." *Mémoirs Ac. Imp. d. Sc. de St. Pétersbourg, Classe Ph. Math.*, vol. XXI., No. 4, 1914 (in Russian).

[4] H. G. Backlund, who was on the staff of the Khatanga expedition, and visited the locality along with the writer, mentions in his paper "Arktisk forskning vid Sibiriens nordspets," p. 504 (*Ymer*, 1925, H. 3 o. 4) that the salt was covered with gypsum.

[5] Pirsson, L. V., Physical Geology, sec. ed., p. 36.

hill as cap rock. Marine Cretaceous strata, with the exception of the Neocomian, forming the basis of Solenaya Sopca, are unknown in northern Siberia, as well as marine Tertiary sediments. Post-Tertiary sands and clays with shells of sea molluscs are widely distributed in northern Siberia, but never reach an elevation of more than a few tens of feet, and one hundred feet perhaps could be considered as a limit. Moreover, no rock salt has been found in these deposits, although some clays are salty. The butte theory must therefore be dropped.

Solenaya Sopca could also be considered a horst of very recent origin, as the top of the hill is covered with recent gravel, which could not have been deposited there after the hill had been isolated. The northern coast of Siberia, in the opinion of the writer, offers many indications of vertical displacements of a very recent date, but no one of them could be responsible for such a large vertical movement as would be required by this theory of origin; also, probably, the very old age of the salt renders it improbable.

The Neocomian of the northern part of the Yurungtumus Peninsula is probably underlaid by Jurassic and perhaps, Triassic strata. The Mesozoic deposits referred to have a wide distribution in northern Siberia, but nowhere are they salt bearing. Therefore the corresponding geological age could not be attributed to the salt locality under consideration. The same statement applies to the Carboniferous and Devonian marine deposits which have been discovered in different parts of northern Siberia and may possibly exist below the Mesozoic in this particular place as well. Only Lower Paleozoic strata, namely Silurian, widely distributed in northern Siberia, are known as not only salt bearing, but containing rock salt as well. To the same salt formation belong deposits of gypsum, found often in large masses, and mineral springs in Siberia utilized for salt production. It would be only logical to attribute to the salt of Solenaya Sopca the same Silurian age as to other rock salt deposits of northern Siberia. Accordingly the vertical motion necessary for the origin of the Solenaya Sopca horst must be measured by thousands of feet, which certainly does not seem probable. Still worse, the horst

theory is not in accord with the fact that this part of the country has suffered at least two extensive vertical displacements. The more recent one took place in the northern regions of northern Siberia during early Mesozoic or latest Paleozoic time, the sunken areas being well shown by the distribution of Mesozoic strata. Another earlier one took place during the Lower Devonian, and was the displacement which transformed the former Siberia into a group of huge continental masses composed of pre-Cambrian rocks and of Lower Paleozoic strata, the Upper Silurian on top, separated by wide straits, into different parts of which later pene-

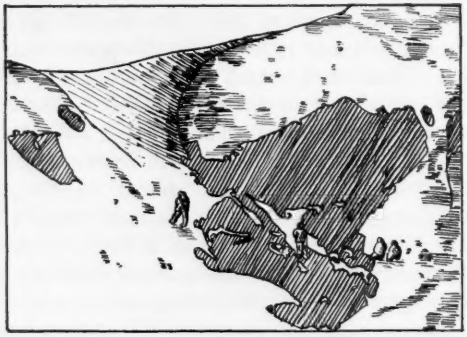

FIG. 2. Rock salt outcrops (heavily ruled) near the top of the salt dome Solenaya Sopca. After a photograph by the writer.

trated Devonian and Carboniferous seas. The sediments of the latter are completely lacking on the surface of the old continent. The main features of the geological structure of northern Siberia were defined at that time by means of the diastrophism referred to.

It would be very difficult to understand how the Solenaya Sopca horst could remain intact during all these extensive motions, if it were on old horst. It would be much more difficult, if at all possible, to imagine a horst of very recent origin, but of very old geological structure, as Solenaya Sopca must be. The horst theory is thus not more tenable than the erosion theory.

The only suggestion which could explain all geological phenomena observed in Solenaya Sopca would be the recent theory of the origin of salt domes, as it has been coined during the last two decades. All the morphological peculiarities of Solenaya Sopca correspond exactly to those of typical salt domes of North America and Europe, the salt core of which is considered as pushed upwards by pressure on the strata containing a salt layer. Owing to its plasticity salt flows under pressure, corresponding, in form and in relation to the strata covering the salt core, to an intrusive body of eruptive rock. Solenaya Sopca corresponds particularly to a rare type of salt dome uplifted above the surrounding country.

As the age of the salt, which should be distinguished from the age of the dome itself, presumably must be Silurian, the distance between the salt core of the dome and its roots has to be rather great, certainly some thousands of feet. But this does not affect the accepted theory at all. Indeed, there are cases known in Germany where this distance goes up to 20,000 feet.[6] As to the age of Solenaya Sopca, *i.e.*, the time of its uplifting, it must be very recent, and perhaps continued up to recent times, as is, of course, typical for all salt domes.[7]

Usually it is suggested that the salt core of a dome takes its origin from an individual layer of rock salt. In the opinion of the writer such a case would be rather exceptional, and the domes, usually, if not always, probably represent an accumulation of many salt flows originating from as many separated and often probably small layers, amounting in most domes to a gigantic stock of salt. The mechanism of such an accumulation is absolutely the same as the intrusion of a salt core originating from one layer.

What is difficult to find out in this particular case is the origin of the pressure upon which the uplifting of salt domes is dependent. Orogenic pressure, which is mostly found instrumental

[6] W. A. I. M. von Waterschoot van der Gracht, "The Saline Domes of North Western Europe," *Bull. South West. Assoc. Petrol. Geol.*, vol. 1, p. 89, 1917.

[7] E. DeGolyer, "The West Point, Texas, Salt Dome, Freestone County," *Jour. of Geol.*, vol. 27, p. 661, 1919.

in analogous cases, is practically lacking, as the Mesozoic strata here are very little disturbed and nearly horizontal. No lines of weakness which would allow the intrusion of salt, or of eruptive rocks, were discovered in the cliffs on the shore. So far as the geology of the country is known, only the static pressure of overlying strata could be considered responsible for the pushing upward of the salt core of Solenaya Sopca. Of course, the geology of the peninsula is very little known. Except a hasty examination of a narrow strip of land along the shore by the writer and his short visit to Solenaya Sopca, there has been no geological work done on this part of the earth's surface. All the conclusions, so far as they are dependent upon the geological data, may be very considerably changed later.

Besides being of great theoretical interest, Solenaya Sopca must be considered very important from an economic point of view, as are, of course, all salt domes, being producers of different salts and sulphur, as well as oil and gas.

The amount of salt stored within Solenaya Sopca must be immense, but thousands of miles of roadless and practically desert country separate the locality from an eventual market in southern Siberia. Salt could be transported by sea to the Russian Far East, where there is a shortage, part of the supply being delivered via Port Said, but this would imply the development of a northern sea route which is still in such an unsettled condition as to make the cost of transportation through Bering Strait not less prohibitive than that by land. As a source of salt Solenaya Sopca is therefore under present conditions deprived of economic value.

It would be very different, if salts of potassium should be discovered in the locality, or sulphur. Especially important would be the discovery of oil. Although there are salt domes, as those of Germany, which are barren of oil and gas, this is exceptional. For example, as suggested by Lucas,[8] most, if not all, of the oil produced in the coastal region of Texas and Louisiana is probably associated with salt domes. This close association should be

[8] A. F. Lucas, "Possible Existence of Deep-seated Oil Deposits on the Gulf Coast," *Trans. Am. Inst. Min. and Met. Eng.*, vol. 61, p. 501, 1920.

kept in mind in relation to every new salt dome in any country. As it is suggested by Waterschoot van der Gracht,[9] the connection of oil and gas with salt domes depends not only upon their structural nature, which allows oil to migrate upward in the sloping sands, but possibly also upon the chemical action of salt on the strata bearing primary oil, or, in other words, on the material from which oil might be produced by distillation. In spite of the very scarce geological data at hand, the writer feels justified in suggesting that the presence of such potentially oil-producing deposits is at least probable in the region under consideration.

It is rather doubtful whether Solenaya Sopca is the only salt dome in the area. In all countries where salt domes are known, the majority of them are entirely hidden below the surface, or, if protruding, are less conspicuous than in the case referred to. These hidden salt domes might be discovered by the application to geological investigations of physical methods such as are now used with such promising success in the Gulf region.

In view of the facts given above, the peninsula between the Khatanga and Anabar rivers appears to be one of the most interesting parts of northern Siberia not only theoretically, but from an economic point of view as well. It is worth trouble and money to investigate the region geologically in detail, paying particular attention to oil prospecting, as there is certainly some possibility that this region may become a new oil country.

CARNEGIE MUSEUM,
PITTSBURGH, PA.

[9] W. A. I. M. von Waterschoot van der Gracht, "The Saline Domes of North Western Europe," *Bull. South West. Assoc. Petrol. Geol.*, vol. 1, p. 91, 1917.

TOURMALINE-BEARING CINNABAR VEINS OF THE MAZATZAL MOUNTAINS, ARIZONA.[1]

CARL LAUSEN.

DURING the course of an examination of the quicksilver deposits of Arizona, the results of which will be published as a bulletin of the Arizona Bureau of Mines, cinnabar was found closely associated with tourmaline. As cinnabar, in so many of its occurrences, has clearly been deposited near the surface and at relatively low-temperatures, while tourmaline is a mineral characteristic of pegmatitic dikes and of veins belonging to the deep zone and formed at high-temperature, the occurrence of the two minerals in association is deemed worthy of record.

The writer is under obligations to Dr. F. L. Ransome, of the University of Arizona, for examining the thin sections and specimens of ore collected, and for suggesting the interpretation of some of the observations made by the writer. Mr. E. W. Bedford, manager of the Arizona Quicksilver Corporation, very kindly gave the writer permission to use any information collected while examining the company's property.

LOCATION.

The Mazatzal Mountains, in which the quicksilver deposits occur, is a north-south range of the Basin and Range type and is situated in central Arizona. The southern end of the range is near the Roosevelt Dam, and the northern end terminates rather abruptly near the East Verde River. This range has a total length of about 60 miles.

Quicksilver was found on Alder Creek, on the west side of the range, and approximately midway between the north and south ends during the early part of 1911. In the last few years cinnabar

[1] Published by permission of the Director of the Arizona Bureau of Mines.

has been found on Slate Creek, on the east side of the Mazatzal Mountains. The deposits on Alder Creek were examined by

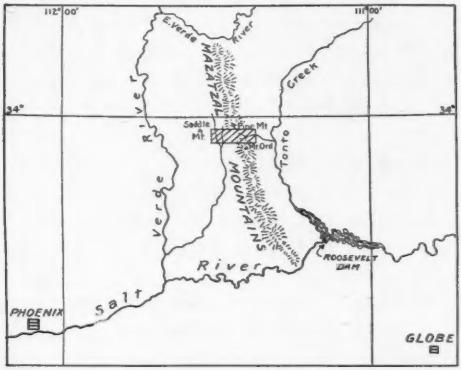

FIG. 1. Index map showing the location of the quicksilver deposits in the Mazatzal Mountains, Arizona.

Ransome[2] in 1914, but at the time of his visit no megascopic tourmaline was noted in the ore.

GENERAL GEOLOGY.

The southern half of the Mazatzal Mountains consists essentially of pre-Cambrian granites with small areas of schist. Resting unconformably on these granites near the Roosevelt Dam are the quartzites and dolomite of the Apache Group[3] and they are conformably overlain by Paleozoic limestones. These sedimentary rocks occupy a rather small area near the dam but at one time undoubtedly extended much farther northward, over the granite from which they have been stripped by erosion during Tertiary and Quaternary time. The northern portion of the

[2] Ransome, F. L., "Quicksilver Deposits of the Mazatzal Range, Arizona," U. S. Geol. Survey Bull. 620, pp. 111–128, 1916.

[3] Ransome, F. L., "The Copper Deposits of Ray and Miami, Ariz.," U. S. Geol. Survey Prof. Paper 115, pp. 39–45, 1919.

Mazatzal range is made up chiefly of a series of crystalline schists derived from sedimentary and igneous rocks that have been invaded by batholithic masses of granite. To the north of the area in which the quicksilver deposits occur the schist is unconformably overlain by the massive beds of Mazatzal[4] quartzite of pre-Cambrian age. Flanking the range on the west side are Tertiary volcanic flows, tuff, and agglomerates of andesitic, dacitic, and basaltic composition. Buff and brown shales, sandstones, and conglomerates of late Tertiary age occur in the valley of Tonto Creek on the east side of the range and tilted and consolidated granitic sands underlie the basaltic flows on the west side. Unconsolidated gravels and sands as terraces along streams are common on both sides of the range and are of Quaternary age.

The belt of schist in which the quicksilver deposits occur has a width of 10 miles and trends northeastward. It comprises a variety of rocks such as quartzite, schistose conglomerate, quartz-sericite schist, brown slate, chlorite schist, dolomitic marble, vermilion-red jasper, schistose rhyolite flows, and rhyolite porphyry. These rocks are arranged symmetrically in zones on each side of a belt of jasper, and this belt of jasper appears to be the axis of a closely compressed anticline or syncline. Many of these schists were obviously derived from sedimentary rocks but others, such as the chlorite schist, show in thin sections the original character of the pyroclastic material from which they were formed. Flow lines and the glassy base in which phenocrysts of quartz are common are clearly visible on a weathered surface of the schistose rhyolite, although much of the rock has been changed to a quartz-sericite schist. The rhyolite porphyry appears to be intrusive in the schists and along the borders of the mass has been changed by pressure to a quartz sericite schist.

The strike of the schistosity varies somewhat from place to place throughout the district, and on the west side of the range is from N 40° E to N 70° E, while on the east side of the mountains, along Slate Creek, it is more nearly east and west. The dip

[4] Wilson, E. D., "Proterozoic Mazatzal Quartzite of Central Arizona," *Pan-American Geologist*, vol. 38, pp. 299–312, 1922.

of the schistosity is everywhere steep. The dip may be to the northwest or southeast and in places is vertical. Surface creep is rather common on the steeper slopes and is most pronounced in the brown slates. In general, the schistosity is parallel, or nearly so, to the original bedding planes of the sediments.

Several miles to the west of the deposits on Alder Creek is Saddle Mountain. Here Ransome [5] noted a series of volcanic flows and tuffs of andesitic and basaltic composition, with a total thickness of approximately 1,000 feet. Just south of Red Rock Pass, the divide between Sycamore and Slate Creeks, are flows and associated tuffs of hornblende andesite having a total thickness of somewhat over 300 feet. Near the Sunflower Ranch, six miles south of the quicksilver deposits on Alder Creek, are also flows of andesite and basalt. Undoubtedly these lavas during late Tertiary time formed a continuous sheet covering most of the region in which cinnabar is now found.

ORE DEPOSITS.

The quicksilver deposits occur in three more or less distinct belts: the Alder Creek belt on the west, Pine Mountain on the north, and Slate Creek on the east. In the first and last mentioned belts the mineralization is most intense. All are similar geologically and a description of one will apply to the other two.

On Alder or West Sycamore Creek, Ransome [6] recognized three parallel lodes, of which the middle or Packover lode is the most important. These lodes are generally parallel to the schistosity. Although the Packover lode has been traced for a distance of several miles, mineralization is not continuous throughout its entire length, but seems to be confined to more or less definite ore shoots, or mineralized areas, lenticular in plan and with an apparent pitch to the southwest. These lodes do not have clear-cut walls, nor were they found to follow well-marked fissures except in a few places. Where mineralization has occurred along faults

[5] Ransome, F. L., "Quicksilver Deposits of the Mazatzal Range, Arizona," U. S. Geol. Survey Bull. 620, pp. 111–128, 1916.

[6] *Op. cit.*, p. 119.

the cinnabar may be in one or both walls, and decreases in quantity with increased distance from the fracture.

Along the Packover lode the metallization is confined largely to the green, chloritic schist and the quartz-sericite schist, but some cinnabar has been found also in the parallel lodes in jasper, in quartzite, and in the rhyolite porphyry. The quicksilver deposits on Slate Creek are practically confined to a belt of brown slate or phyllite.

The ore on Alder Creek consists of veinlets generally parallel to but occasionally cutting the lamination of the schist, or as thin films on fracture planes, and only rarely as disseminated particles of cinnabar in the body of the schist.[7] These veinlets vary in width from a fraction of an inch to six inches ore more, but those less than half an inch in width are most common. In general, the smaller veinlets carry a higher percentage of cinnabar. As was stated above, these ore shoots do not have definite walls, and ore grades into barren rock by a gradual increase in the distance between veinlets.

Cinnabar is the only important quicksilver mineral in the ore, although small amounts of the chloride, calomel, and native quicksilver have been found. Metacinnabarite may be present in small quantities. Pyrite is present in some of the ore and Ransome noted chalcopyrite. The cinnabar is later than and has probably replaced the pyrite to a slight extent. Occasionally a little azurite and malachite are found as oxidation products of chalcopyrite.

Gangue minerals consist essentially of quartz, calcite, and a ferruginous carbonate near ankerite in composition. Tourmaline occurs as a gangue mineral in tiny veinlets closely associated with quartz and cutting the ferruginous carbonate. This black tourmaline is not abundant as a megascopic constituent of the ore, but is more widespread as microscopic needles visible in thin section.

[7] An exception to this occurs on the Goswick property, on Slate Creek. Here, most of the ore developed occurs as specks of cinnabar disseminated in bleached, brown slate. Many of the particles of cinnabar are so small as to be visible only with the aid of a magnifying glass, yet they are abundant enough to impart a pink or reddish color to the rock.

Quartz is by far the most important gangue mineral and occurs in two generations, both of which contain tourmaline. This quartz is of a milky white color and incloses numerous minute inclusions, circular in outline, and which may contain either gas or liquid.

An intergrowth of the ferruginous carbonate with quartz produces an interesting structure which, in many respects, resembles, although on a much smaller scale, the columnar structure in lavas. These columns are often curved and extend across the vein from wall to wall. They do not consist of single crystals, but rather as interlocking grains of quartz that have a different crystallographic orientation. This columnar structure is not to be confused with the typical comb structure so commonly associated with crustification; there is no banding due to crustification in the quicksilver veins of this district, and drusy cavities are rare. The columnar structure is especially noticeable in oxidized ore, for the ferruginous carbonate on weathering leaves a residue of limonite.

ORIGIN OF THE ORE.

So many occurrences of quicksilver ores are in regions of Tertiary or Quaternary volcanic activity that a genetic relationship between the deposition of quicksilver and vulcanism is considered as well established. Lindgren [8] places quicksilver ore in the class of deposits formed near the surface by ascending thermal waters and closely related to igneous activity.

The occurrence of tourmaline with cinnabar in the quicksilver veins of the Mazatzal Mountains is both interesting and unusual; and, as far as the writer knows, has not been found elsewhere. The evidence of a high-temperature origin for these deposits, while not conclusive, is certainly rather suggestive. Intergrowths of tourmaline, quartz, and the ferruginous carbonate occur and are practically contemporaneous as regards the time of deposition. A later generation of quartz and tourmaline cuts the carbonates, and this is followed by cinnabar that cuts all preëxisting minerals, and replaces both quartz and carbonate.

[8] Lindgren, W., "Mineral Deposits," 2d edition, p. 487, 1919.

Since the tourmaline is earlier than the cinnabar the question arises: are the two minerals genetically related? Several possibilities suggest themselves.

1. Cinnabar was deposited later than the associated gangue minerals.

2. Tourmaline and quartz are residual portions of older pegmatitic veins, and have been replaced by the carbonate and cinnabar.

3. The tourmaline and cinnabar have a common origin.

These several possibilities will be discussed more fully below, and the evidence in favor of or against each will be presented.

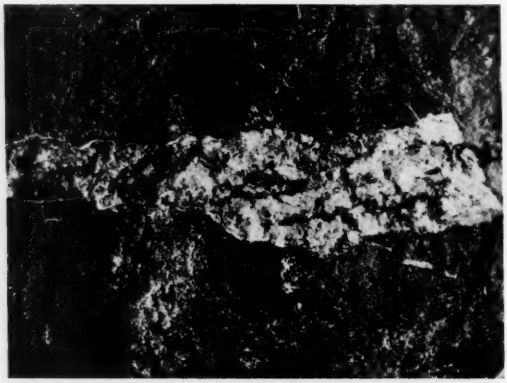

FIG. 2. Vein traversing schist. Dark gray areas in the vein are cinnabar; white is quartz and carbonate. Natural size.

1. Cinnabar sometimes does occur as thin films of the pure mineral on fracture planes of the schist with apparently no gangue minerals present, but narrow veinlets of unusually rich ore always show some quartz and carbonate as associated minerals when examined in thin sections. The vein shown in Fig. 2 is typical of all the quicksilver veins of this district. Microscopic examination of the walls of this vein, as well as many others, fails to show a

trace of cinnabar. Only rarely has cinnabar been found in the wall rock and then always in close proximity to the vein. In view of the intimate association of the quartz and carbonate with cinnabar, it seems reasonable to conclude that the quartz-carbonate gangue and cinnabar are genetically related.

2. These deposits are in crystalline schists that have been invaded by batholithic masses of granite of pre-Cambrian age. Pegmatitic quartz veins are to be expected; and, as a matter of fact, are abundant. The white quartz of these pegmatitic veins closely resembles the quartz in the quicksilver veins, but apparently does not contain the ferruginous carbonate. In the unoxidized ore, the intergrowths of quartz, carbonate, and tourmaline, that form the columnar structure described on a preceeding page, suggest contemporaneous deposition. A second generation of quartz with microscopic needles of tourmaline cuts both the carbonate and an earlier generation of quartz and tourmaline. In one specimen small veinlets of quartz and tourmaline traverse carbonate. One might well say such veinlets are residual, but thin sections of this specimen examined microscopically show grains of quartz or carbonate on each side of the vein with the same optical orientation. This suggests that the tourmaline was introduced in fractures.

3. That the cinnabar and tourmaline are genetically related seems reasonable; but inasmuch as the cinnabar is later than all the gangue mineral in the veins, the conclusions reached are difficult to prove with certainty. It is not impossible that the cinnabar was deposited without gangue minerals; but if so, it is a remarkable coincidence that the cinnabar is nearly always found in small veinlets of quartz and carbonate. Ransome [9] counted 75 of these small stringers parallel to the schistosity and two of them cutting the schistosity in a distance of 33.5 feet. Tourmaline apparently is absent, and if present occurs only in minute amounts as a microscopic constituent of the ore.

Tourmaline is certainly uncommon in quicksilver deposits where cinnabar is the important ore mineral. Regarding the occurrence

[9] Personal communication.

of quicksilver in deposits formed at somewhat higher temperatures and pressures, Lindgren [10] states:

> High temperature is evidently unfavorable for their (quicksilver minerals) development. The most noteworthy occurrence is that of coloradorite in the gold telluride veins of western Australia, which contain, among other minerals, magnetite and tourmaline, indicating deposition at fairly high temperature. In gold-bearing quartz veins of the ordinary type, believed to have been formed at a considerable depth, but at considerably lower temperature and pressure than pegmatite dikes, cinnabar is not an uncommon mineral.

The gangue minerals most commonly associated with quicksilver deposits are opal, chalcedony, and quartz, also calcite and dolomite; and among the metallic minerals pyrite and stibnite. Barite and fluorite are rarely found, but Becker [11] states that bituminous matter is found at many quicksilver deposits. Most of these associated minerals are absent in the cinnabar veins of the Mazatzal Mountains. The writer was given a specimen of stibnite by one of the prospectors and which was reported to have been found near the quicksilver veins, but the exact locality was not disclosed. A careful search of ore collected from various parts of the district failed to show the presence of visible stibnite in a single specimen.

No intrusive mass of large size from which the tourmaline may have been derived has been found in this region except the granite of Mt. Ord which is believed to have invaded the schists during pre-Cambrian time. These deposits probably are not connected genetically with this intrusion, as the amount of erosion which the granite and schist have undergone during pre-Cambrian time alone was undoubtedly great and this extensive erosion would probably have stripped away all evidence of mineralization for a depth of 5,000 feet or more. No economic deposits of cinnabar as yet have been found to extend to such a depth; and the most reasonable assumption is that the deposits were formed during Tertiary time by solutions of deep-seated origin and perhaps from the

[10] Lindgren, W., "Mineral Deposits," 2d edition, p. 488, 1919.

[11] Becker, G. F., "Geology of the Quicksilver Deposits of the Pacific Slope," U. S. Geol. Survey Mono. XIII., p. 53, 1888.

same magma that gave rise to the andesitic flows and associated tuff.

Alder Creek has cut down its bed to a depth of a thousand feet in the pre-Cambrian schists. To the west, at Saddle Mountain, Ransome [12] found the volcanic rocks to have a total thickness of about a thousand feet. A similar thickness of volcanic rocks exists a few miles south of the deposit on Alder Creek. If the ore in this region is genetically related to Tertiary volcanic activity, and an equal thickness of lava and tuff originally covered the schist in which the ore occurs, then most of the ore now developed was deposited at a depth of 2,000 feet or less. At this rather shallow depth only moderate temperature and pressure could have prevailed, and evidence of crustification should be common. The formation of tourmaline under these conditions suggests that the presence of tourmaline is not invariably indicative of former high temperature and great depth or pressure. It is realized, however, that the observations recorded in this paper are not in themselves sufficient to confirm this suggestion.

[12] *Op. cit.*, p. 117.

ARIZONA BUREAU OF MINES,
TUCSON, ARIZ.

BAUXITE IN ALABAMA, WITH A SPECIAL DISCUSSION OF THE MARGERUM DISTRICT.[1]

WALTER B. JONES.

HYDRATED alumina, or bauxite, was first discovered at Baux, in France, in 1821, and has since been found in many countries. Its early history in the United States seems to be in some doubt, but

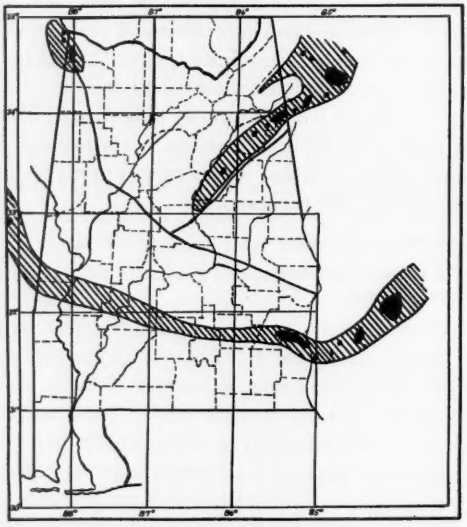

FIG. 1. Sketch map of Alabama, with known deposits of bauxite and bauxitic clay, and possible territory (shaded areas).

the discovery appears to have been in Pike County, Georgia, in 1887. Cherokee County, Alabama, seems to have followed this in 1889, and Pulaski County, Arkansas, in 1891.

[1] Published by permission of the Geological Survey of Alabama.

Little bauxite has been mined in Alabama, the original discovery having been made in brown iron ore banks and it was long known as "iron ore blossom," until an inquisitive mine foreman sent in a sample of the ore for analysis, which proved the material to resemble that of Baux, France.

Since that time many deposits of bauxite have been found in Alabama, and can be grouped into three areas (see Fig. 1), in the order of their discovery:

1. Cambro-Ordovician contact, occurring from the Georgia line, through Cherokee, Calhoun and Talladega counties.
2. Midway-Nanafalia contact, with deposits of bauxite known in Barbour and Henry counties.
3. Cretaceous-Mississippian contact, with bauxite known near Margerum in Colbert County.

CAMBRO-ORDOVICIAN CONTACT.

This area includes a dozen of more known ore bodies that occupy a belt of Lower Ordovician limestones and dolomites, formerly assigned to the base of the Knox formation. The belt extends in a northeast direction, parallel to the trend of the Appalachian System. Most of the deposits occur near the Alabama-Georgia line in Cherokee County, where the greatest development in the brown ores of that section took place. Sections 24, 25, 26, and 35, Township 11, Range 11 east, have an important group of deposits, notably the Estes, War-whoop, Gaines Hill, Dyke, and Washer banks. Smaller or less well-known deposits and outcrops extend into Calhoun County, and during the World War a small amount of ore was shipped from a small ore body in the town of Talladega, in Talladega County.

The bauxite seems to be at or near the unconformable contact between the Weisner quartzite, of Cambrian age, and the Ordovician limestones. The ore bodies are more or less lenticular, and are irregular in outline. Most of them show bedding planes, and are irregularly traversed by veinlets of later limonite. Their thickness varies from a few feet to some 40 to 50 feet.

It is the writer's belief that additional deposits of bauxite may be found anywhere in the region from the State line northeast of Rock Run in Cherokee County, to Talladega, in Talladega County since the same geological conditions prevail over all the belt.

MIDWAY-NANAFALIA CONTACT.

This belt is located in the Coastal Plain region of the State, and the known deposits of bauxite are confined to Barbour and Henry counties, with the locus about the point of Alexander's Mill. These deposits were discovered and prospected by the Republic Mining and Manufacturing Company of Hermitage, Georgia. Rettger [2] gives an account of this work as follows:

> During the prospecting which covered a period of about 12 months, some 200 different shows were tested on more than 60 properties. From these 200 shows 75 deposits were outlined containing a fair amount of merchantable ore. The prospecting consisted of test pitting and drilling, and in all more than 2,000 bore holes were put down, supplemented by many test pits. About 1,000 partial analyses were made of bauxite and associated clays.

The ore occurs in pockets and depressions along the eroded surface of the Midway or Clayton limestone. Every variety of ore is present, from the white chalky ore to the hard, white and red varieties. Much of the ore is high in silica, and ranges from 50 to 55 per cent. aluminum oxide, which may be regarded as about the average of merchantable ore from this general region. The belt carrying most of the deposits is about 12 miles long, has a maximum width of 8 miles, and an average width of about 2 miles. The nearest railroad connections are Eufaula and Clayton, some twelve miles away.

There has been no production of ore from this group of deposits, but they are under lease to the Republic Company.

It is believed that the entire belt extending across the State and into Mississippi and Georgia, carries deposits of bauxite. Indeed, recent discoveries in Mississippi support such an assertion,

[2] Rettger, R. E., "The Bauxite Deposits of Southeastern Alabama," ECON. GEOL., vol. XX., No. 7, Nov. 1925, pp. 671–672.

and future prospectors for bauxite in Alabama would do well to examine the top of the Midway limestone.

CRETACEOUS-MISSISSIPPIAN CONTACT OR MARGERUM DISTRICT.

Deposits of bauxite belonging to this group are found in Colbert County, of northwestern Alabama, just south of the Tennessee River. Bauxitic clays presumably of this group, occur just across the State line in Tishomingo County, Mississippi. Most of the deposits are confined to a 600 acre tract of land located about six miles south of Margerum, a station on the Memphis-Chattanooga division of the Southern Railway System.

The only mention of bauxite in this district is by Burchard [3] who says:

> In the fall of 1921 J. W. Adams, of Tuscumbia, Alabama, in prospecting for clays, discovered deposits of bauxite and bauxitic clays near Margerum, Colbert County, Alabama. These deposits are in erosion channels and sink holes in Mississippian limestones that have been partly filled by Cretaceous (Tuscaloosa) gravel.

The deposits referred to are isolated ore bodies about three miles slightly east of south of Margerum, and therefore northeast of the main group. Mr. Adams spent two years prospecting and testing deposits of bauxite in Mississippi, then returned to Colbert County where he extended his discoveries in that section. In about twelve months time Mr. Adams and his workmen dug over sixty test pits and trenches, and about fifty samples were selected for analysis. An accurate map was made showing the location and elevation of the test pits. The results of this work were very generously placed at the disposal of the writer, greatly facilitating his field work in the summer of 1925.

Topography.—The surface of the region surrounding this group of deposits consists of a broken, highly dissected upland, representing the western terminus of Tuscumbia Mountain. The area is about 600 feet above sea level, with an average difference of elevation between valleys and hills of about 200 feet. Drain-

[3] Burchard, E. F., "Bauxite in Northeastern Mississippi," U. S. G. S. Bull. 750-G, 1925.

age of the area is into the Big Bear Creek, which empties into the Tennessee River near the Alabama-Mississippi boundary. The rugged topography renders cultivation impracticable; a few patches, garden plots, small orchards, and dilapidated houses mark the scant dozen clearings which break the monotony of the pine and hardwood forests extending for several miles in all directions from the bauxite area.

At present the area is rather inaccessible, since the only outlet is by a wagon road, impassable for motor traffic during the winter season, although should the deposits justify it a new road could be located southward from the bauxite district to connect with a secondary road, and thence to Margerum, the nearest shipping point.

Stratigraphy.—The geological formations exposed in the Margerum District are mainly of Mississippian age, with a blanket of Cretaceous (Tuscaloosa) sand and gravel. The following outline may be of assistance in identifying the bauxite-bearing formations:

There are several fine key beds which enable one to work out the stratigraphic relations accurately and easily, of which perhaps the best are the ledge forming asphaltic members of the Bethel and Gasper formations. Between the asphaltic beds are limestones with abundant silicified fossils that are everywhere thickly matted in the residual soils accumulated over the limestone beds. Another excellent key bed is the layer of *Productus* limestone about one foot thick at the base of the St. Genevieve formation. This bed is probably encountered more frequently than any other, occurring as it does just below thin bedded shales that are readily disintegrated by weathering agencies, and capping the massive bedded cherty limestones of the Tuscumbia formation, which weather away very slowly. The Hartselle Sandstone makes a good tie point for the upper part of the section.

The surface in the immediate vicinity of the bauxite deposits is almost entirely covered with Tuscaloosa sand and gravel. This blanket was obviously laid down on the much dissected surface of the Mississippian land mass after the long period of emergence.

CRETACEOUS		TUSCALOOSA FORMATION	Sand and gravel, with some clay and clay lenses.
UNCONFORMITY			
PENNSYLVANIAN		COAL MEASURES	Mostly massive bedded sandstones, white to very dark in color. Some thin shale beds. No coals in the lower 200 feet.
MISSISSIPPIAN	CHESTER GROUP	BANGOR LIMESTONE	Massive bedded fossiliferous limestone, and occasional shale beds. Carries two oolitic members, the upper being very persistent. In all about 400 feet thick.
		HARTSELLE SANDSTONE (Golconda, Cypress)	Massive bedded sandstone, with one asphaltic member. About 200 feet thick.
	MONTE SANO GROUP	GASPER	Shale at top, shaly limestone in the middle and limestone at the bottom. Asphaltic oolite near base. Extremely fossiliferous throughout. 240 feet thick.
		BETHEL	Asphaltic sandstone, 20 feet thick.
		ST. GENEVIEVE	Mostly blue shale and marl, with a ledge of limestone at base which is abundantly fossiliferous. 60 feet thick.
	TUSCUMBIA GROUP	TUSCUMBIA OR WARSAW LIMESTONE	Massive to thin bedded, dark blue cherty limestone, abundant fossils. About 150 feet thick.
	OSAGE GROUP	LAUDERDALE CHERT	Chert and cherty limestone, stratified and fossiliferous. About 225 feet thick.
UNCONFORMITY			

Moreover it appears that the drainage has not been materially changed from the Post-Mississippian pattern, a view supported by the fact that rock outcrops are found at all altitudes, wherever erosion has removed the Cretaceous sediments. A fine example of this occurs in the midst of the bauxite deposits, where several huge boulders of asphaltic oolite (Gasper), surrounded by Tuscaloosa sands, jut out from the side of a ridge.

Form and Character.—The ore bodies of this area are widely distributed and always occupy nests in the thicker portions of the remaining remnants of Tuscaloosa gravel and clays. In no case were they seen to rest directly upon Mississippian beds. Also, they invariably pass downward into bauxitic clay and clays. In shape, the bodies are irregular. In size, they vary from a few pounds of ore, as observed in one of the shafts, to moderately large bodies several hundred feet in diameter.

The ore is generally pisolitic, with a matrix of chalky material of essentially the same composition as the pisolites. Most of the ore bodies have numerous small streaks of iron carbonate, often weathered to limonite, with some traces of manganese. Frequently these siderite veinlets show evidence of pisolitic texture, suggesting that they were formed at a later period than the bauxite. There is little or no ore in this region that comes under the classification of "hard ore," so characteristic of the other deposits of the State. The predominating type is the loosely cemented pisolitic soft ore which disintegrates into "buckshot" upon short exposure. Incidentally most of this ore is low in iron, while the typical hard ores from the other sections of the State are high in iron content. From this one would be led to regard the hardness of the ore as depending largely upon the amount of iron present.

The prevailing color of the ores and associated clays ranges from almost pure white to buff, with reddish grades sometimes encountered.

Deposits.—The following sections will serve to illustrate the general character of the ore bodies, as outlined by the exploration work:

PIT NO. 75. PARTIAL ANALYSES.

Feet.		Ignition.	Silica.	Alumina.	Iron.	Total.
4.9	Surface					
8.5	Ore	19.56%	30.60	46.42	3.14	99.72
3.6	"	19.28	26.80	49.26	3.71	99.05
4.0	"	20.20	26.00	48.60	5.00	99.80
9.3	"	17.64	29.56	44.20	7.28	98.68
14.0	"	16.28	33.12	45.96	3.00	97.36
44.3	Ore in bottom of pit					

PIT NO. 74.

3.0	Ore	24.64	20.56	52.86	1.50	99.56
13.0	"	22.80	21.08	53.68	1.60	99.16
16.0	Ore in bottom of pit					

The ore from pit number 74 is perhaps the type for the district, and almost an average in composition.

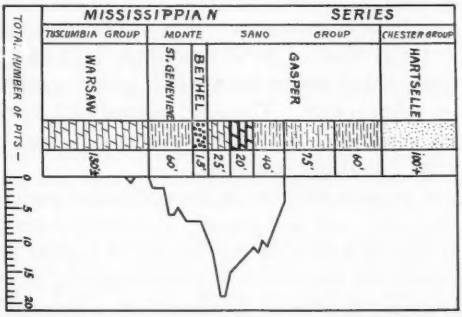

FIG. 2. Vertical section of beds exposed in the Margerum District, with curve showing the stratigraphic position of the test pits cutting bauxite. Note concentration of bauxite at the Gasper and Bethel asphaltic members.

There are thirty or more separate ore bodies that have been discovered to date. All of the test pits that have been driven are 3 feet by 4 feet, and are readily accessible. Trench number 72 is 135 feet long and cuts ore all of the way.

The stratigraphic distribution of the ore bodies may be seen in Fig. 2. There is a marked association of the bauxite with the asphaltic beds, although the writer can offer no explanation for it. The presence of the shale beds within the mineralized zone probably has no particular significance, though the limestones are regarded by the author as being essential factors in the formation of all of the bauxite deposits of the State. A total of 19 test pits were dug into bauxite at the horizon of the fossiliferous limestone member which separates the Gasper and Bethel asphaltic beds.

Suggestions as to Genesis.—The origin of the Margerum bauxites differs from that of the other deposits of the State, in that they appear to have been formed within already existing clay and gravel beds laid down in erosional channels in Mississippian strata. The gravel making up these deposits is quite different from the water-worn material of the Tuscaloosa formation, and may represent flint and chert weathered from the cherty limestones of Sub-Carboniferous age that make up most of the surface of the country to the east of the bauxite area. It is evident that these gravel beds were the product of rapid deposition, such as might have characterized choked stream beds, which probably ushered in the Tuscaloosa submergence. These old channel and depression deposits may be regarded as transitional, and laid down just prior to the typical Tuscaloosa sediments.

The usual sequence disclosed by the exploration work is bauxite, bauxitic clay, clay, sand and gravel. Practically every pit passed into sand, clay, or gravel, or else stopped in bauxite or bauxitic clay. In every case the sand or gravel encountered at the bottom of the pits showed little or no decomposition or disintegration.

In several of the pits are found pebbles that show transitions from flint to bauxite, and there is no way to tell what is inside without actually breaking them open. This mode of occurrence was first pointed out by Mr. Adams, and was studied carefully by the writer. Most of the pebbles appear to retain what was probably their original outline, sometimes marked by a thin layer of rotten silica or clay, and a core of high grade, pisolitic bauxite. This disintegration might well be attributed to leaching by strong

carbonic or possibly alkaline waters that emanated from the limestone area to the east. The presence of swamp or bog conditions which must have accompanied and followed this submergence was one of the necessary factors in the leaching process. The completeness of the disintegration must have depended largely upon the accessibility of the invading waters to the clay and gravel deposits and upon the length of time they were allowed to remain in contact. Obstructions of coarse material could easily have checked the flow of water, forming pools favorable for the precipitation of any iron or alumina that might have been present. The disintegration of the gravel beds would have been more complete in the center of such a place with a corresponding zonal arrangement of the bauxite and bauxitic clay.

It is possible that a part of the bauxite may have been laid down simultaneously with the clay, for not all of the ore bodies show evidence of leaching or alteration. It is possible that the waters flowing over the bog and swamp areas may have been depositing clays, and that bauxite and perhaps siderite may have been precipitated at the same time.

The source of the alumina for the Mississippi deposits has been suggested by Burchard [4] as follows:

> It is possible that the streams flowing from the Cretaceous . . . land areas on the east bore glauconitic and bentonitic material in a finely divided state as well as iron and aluminum salts in solution. . . .

He continues to say that these salts could easily have produced iron carbonate and aluminum hydroxide, in the presence of organic acids. There is no question but that the conditions under which the Margerum deposits were laid down were similar to those enumerated by Burchard for the formation of the deposits in Mississippi. Burchard concludes that the Mississippi bauxites seem to have been laid down under conditions similar to those under which deposits of bog iron are believed to have been formed, although he suggests the possibility of some of the deposits having been formed through the alteration of water-laid clays. The

[4] Burchard, E. F., *op. cit.*

writer regards the alteration or disintegration of the clay and gravel beds into clay and bauxite, under special swamp conditions as mentioned above, as being the most plausible explanation for the formation of at least part of the bauxites of the Margerum district.

It is believed that the iron carbonate was formed later than the bauxite, since it occurs as stringers such as would occupy shrinkage cracks in bauxite and clay. Much of the siderite or its altered product, actually shows pisolitic texture which probably represents subsequent impregnation or cementation, perhaps replacement, concentrated near cracks or other open spaces which admitted free circulation of the iron-bearing solutions.

The exact mode of formation of the bauxite is unknown. The writer appreciates the inadequacy of the explanations advanced both by himself and others, and hopes that some one possessed of the desire and equipment will determine just what combinations of solvents and precipitants are necessary to produce bauxite, and under what physical conditions the precipitation will take place. The association of the bauxites with unconformities and their occurrence in erosion channels, often in contact with debris, make a strong case for swamp conditions. But there are numerous unconformities which do not carry bauxite. In Alabama all of the bauxite is closely associated with limestones, but in other places limestones do not occur near the deposits. Everywhere it appears to form through erosional or weathering agencies, and there must be some definite agents present which bring about this formation.

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EDITORIAL

THE MICROSCOPE AND ORE GEOLOGY.

Is the use of the microscope being overdone in the study of ore deposits? Certain authorities, whose achievements in the field of economic geology entitle their views to the greatest respect, would have us believe that it is. It may be of interest, therefore, to consider whether there is any justification for this attitude.

It is well known that in the preparation of some of the great classics of our science, such, for instance, as Emmons' report on Leadville and the magnificent series of monographs on the Lake Superior Iron deposits, only incidental use was made of the microscope. There are probably quite a few geologists who feel that, if the Lake Superior monographs had been prepared after the introduction of modern metallographic methods into ore geology, long discussions as to the textural relations and order of formation of the several iron oxides present might have obscured the really big issues.

It is also true that E. T. Mellor in setting out to solve the vexed question of the origin of the gold in the Witwatersrand conglomerates deliberately avoided the use of the microscope, and, taking a broad view of the problem based on his detailed survey of the gold field as a whole, was able to offer a solution[1] that to most of us who have studied the subject at first hand is absolutely final.

Similarly in regard to that other much debated problem, the origin of the Sudbury nickel ores, the practical exploratory work of Roberts and Longyear[2] in the eastern part of the Sudbury basin carries far more conviction than elaborate microscopic studies of these ores made during the past twenty years.

[1] *Trans. I. M. M.*, 1916, pp. 226–291.
[2] *Trans. A. I. M. E.*, 1918.

On the other hand there have been published numerous memoirs and monographs in which the results of field work and microscopic study have been admirably combined in the solution or elucidation of difficult problems, where it is quite certain that observations in mine and quarry alone would have failed to achieve the desired result. Particularly is this true of many copper, silver and tin deposits where the ore consists of a complex intergrowth of a number of minerals or where successive generations of minerals have replaced one another. Without the use of both the petrographic and the metallographic microscopes the history of such deposits and their probable behavior at depth could never have been unravelled.

The microscope in both its forms has, indeed, become absolutely indispensable to the ore geologist, and with the application of the principles of metallography and colloidal chemistry to the study of mineral deposits is daily becoming more so.

The real trouble, as the writer sees it, has arisen from attempts to substitute detailed microscopic examination of ores for systematic work on the surface or underground. Especially since the introduction of the reflecting microscope there has been a tendency on the part of geologists to base far-reaching deductions on the study of a few specimens not necessarily even collected by themselves.

Such attempts to supplant field evidence by the microscope cannot be too strongly condemned. Their utter futility will be patent to anyone who has made a careful study of even a moderately complex mineral deposit; some of the main objections being that: (*a*) absolutely typical specimens are, as a rule, extraordinarily difficult to obtain; (*b*) the microscopic evidence afforded even by typical specimens may not be decisive—it is often such that no two observers would agree as to its precise significance; (*c*) unless the geologist examining the specimens is well acquainted with the deposit in question he cannot possibly view them in their true perspective, or, in other words, in their true relation to the deposit as a whole and to the rocks containing it. That these objections are valid is proved by the fact that there

are on record a number of instances where the study of such specimens has led investigators to draw conclusions that no one working on the spot would have drawn.

We find, therefore, not that the use of the microscope is being overdone, but that it is being to some extent abused. Detailed mapping and sectioning and observations in mine and quarry must always remain the principal means of studying an ore deposit, but as an auxiliary to such work the microscope has come to occupy a position in ore geology from which it will never be displaced.

PERCY A. WAGNER.

JAMES FURMAN KEMP

Just as this number is ready to go on the press we have learned than our esteemed Associate Editor, James Furman Kemp, Professor of Economic Geology at Columbia University, died suddenly at Great Neck, Long Island, the morning of November 17, while awaiting a train from his home to New York.

Known throughout the world, and revered and loved by all who had even slight contact with him, his death is a shock to his friends and a loss to his profession. To his family we extend our deepest sympathy. But his family and his University are not alone the sufferers. We all are. The staff of the JOURNAL will miss his kindly counsel. His interest in our work never flagged despite occasional ill health and calls of other duties, and all our readers owe tribute to his labors. Great though be our respect for his work, it was his personality most of all that won our affection. There is a void in our hearts!

A fitting eulogium will appear in our next number.

DISCUSSION AND INFORMAL COMMUNICATIONS

A PHYSICO-CHEMICAL THEORY OF METASOMATISM.

Sir: In replying to Dr. V. M. Goldschmidt's response to my criticism of his article on the above subject, which he has changed to "Metasomatic Processes in Fissure Veins," I prefer to retain the original and more applicable caption. For not referring to Dr. Goldschmidt's earlier German article I cannot be held responsible inasmuch as he did not refer to it, and if his English contribution failed properly to reflect the original, it is unfortunate.

My reason for characterizing the author's neglect of a definite formula for mica as "of dubious accuracy" was, that since concentrations in such equilibrium statements are usually expressed in *moles,* no *quantitative* meaning could be attached to the expression he derived and without that I considered it of little value.

Dr. Goldschmidt regrets that I was unable to see his point that ". . . A solution in order to effect metasomatism must contain the substances to be added in concentrations at least equal to a minimum which is definite for each case . . ." is a condition peculiar to metasomatism. I must confess to being so obtuse as still to be unable to see the point, in spite of his further discussion which to me seems nothing more than a repetition of his original statement. He further writes ". . . that for any process of metasomatism a definite minimum of the substance added is needed and that the process of replacement will not take place if at least that minimum concentration is not present. For other cases of double decomposition the formation of a solid product is dependent not on the concentration of one component only but on the product of the concentration of two components.

I cannot see but that the reaction represented by

$$H_2SO_4 + \underset{\text{solid}}{CaO} = \underset{\text{solid}}{CaSO_4} + H_2O,$$

where

$$[H_2SO_4] = \frac{[CaSO_4]}{[CaO]} = K,$$

the quantity of water present being such that the addition of one mole makes no appreciable difference, parallels Dr. Goldschmidt's case of

$$\text{mica} + \text{alkali silicate} = \text{felspar},$$

where

$$[\text{alkali silicate}] = \frac{[\text{felspar}]}{[\text{mica}]} = K,$$

and the " facts " which he claims are *peculiar* to metasomatism are not really so. It was just this attempt of Dr. Goldschmidt to shut up, so to speak, the chemical phenomena of metasomatism by themselves in a water-tight compartment that led me to my criticism of his article.

Dr. Goldschmidt's discussion of the point is all the more unintelligible to me too seeing that the equation on which he bases his statement is a purely assumed one lacking quantitative chemical verification.

The conclusion of his reply to my criticism seems to me unjustifiable in view of the fact that he neglects hydrolysis and assumes the existence of substances in solution which, since they almost certainly have no true solubility, undergo hydrolysis. These are thus decomposed into constituents some of which, at least, are present in colloidal solution and hence cannot be considered as even taking part in the equilibrium which is so seriously and laboriously considered! The real equilibrium is one, therefore, between substances which can only be conjectured but which are essentially different from those treated by Dr. Goldschmidt. His equilibrium is, consequently, a purely fictitious one.

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EMERALDS AT BOM JESUS DOS MEIRAS, BAHIA, BRAZIL.

A VISIT was made to the mineral deposits of Bom Jesus dos Meiras in December, 1925, but time was available only for a brief reconnaissance. The observations, however, appear to throw some light upon the origin of beryl, a subject upon which geological literature offers no very satisfactory conclusions.

The town of Bom Jesus lies in the interior of the state of Bahia, within a large area of primitive culture, to reach it entails considerable effort and expense. Travel at present is by mule train some seventy leagues from the end of the railroad, over mountains and through desert.

The occurrence is not well known, even in Brazil. Descriptions of a few crystals brought out by German traders have found their way into German literature.[1, 2] Dr. Oliver C. Farrington[3] visited the district in 1922–23, and brought back some specimens which are now the property of the Field Museum, Chicago.

The gems were discovered in 1913 by local people, who have since mined them intermittently. The first stones were found on the surface of the west slope of the sierra, about ten miles west of Bom Jesus. Early development consisted of pitting the surface debris; the work gradually ascended the slope, until emeralds were encountered in place near the top. Mining is now carried on by primitive means in a rude open cut. The mine is simply a jagged scar on the mountainside lying in the midst of wilderness that extends further than one can see.

The emeralds occur as well developed hexagonal prisms ranging up to one and one-half inches in diameter and four inches in length. Almost all specimens show several pyramid faces; some are twelve sided, some three sided. One was found with eighteen prism faces. Doubly terminated crystals are fairly common, being attached at the prism faces. Only about twenty kilograms have been mined since the discovery. Very few of the stones are

[1] Siedel, *Neues Jahrbuch Mineralogic*, 1925, Bd. 38, pp. 759–804.

[2] Uhlig, *Centralblatt*, Min., 1915, pp. 38–44.

[3] Personal account.

of sufficiently dark color to rate as of gem quality. They are almost entirely clear green in color, the large majority, however, being rendered semi-transparent by abundant small fractures and bubble-like flaws.

The emeralds occur in an altered marble, presumably of Lower Paleozoic age,[4] and at least two hundred feet in thickness, capping the mountain at this point. The degree of metamorphism exhibited by the rocks of this area greatly resembles that of the North American pre-Cambrian. Gneisses and schists are abundant.

The marble is dolomitic, and where unaltered, is pure white and coarsely crystalline. Where weathered, it is friable, being easily crumbled in the hand. Traces of former bedding are approximately horizontal. The marble is well jointed, one general group of joints at the mine striking northeast, another group, southeast. The northeast joints are most conspicuous.

Cutting through the marble along the joints are vertical sheets of talc and streaks of dark colored material, that make up locally nearly half the rock mass. The talc apparently was formed by alteration of the marble due to circulation of solutions along the joints. The emeralds are found in the vicinity of these talc sheets, mainly in geodes or drusy cavities, along with crystal growth and druses of quartz and calcite. A few are found singly in the marble, apparently formed by replacement of the dolomite.

The outer linings of the characteristic geodal cavities are of crystalline quartz. The inner parts of the geodes are usually of crystalline calcite, which may or may not fill the interiors completely. The emeralds occur in or with the calcite, being apparently contemporaneous with it, as are also the tourmalines and topazes that are occasionally found. Often a second generation of quartz lines the inner walls of the geodes and in some cases the needles of this generation as well as the calcite are covered with thin coatings of drusy quartz. Some of the quartz needles

[4] Branner, J. C., "Outlines of the Geology of Brazil," *Bull. G. S. A.*, vol. 30, pp. 189–338; Map.

formed in these cavities are remarkably long in proportion to their thickness. Many are over four inches long and are less than a quarter inch in thickness at the base.

The fact that the emeralds are localized in the altered marble, as well as the entire lack of corrasion of the crystal faces, indicates a non-sedimentary origin. Furthermore, the manner of occurrence, largely as crystals grown inward from the walls of cavities, along with and within crystal growths of quartz and calcite, seems incontrovertible evidence that they are a secondary development.

At the mine and in the vicinity, crystals of garnet, hematite, topaz, and tourmaline are found. This mineral association and the alteration of the marble to talc along vertical fissures, indicate that the genesis of the beryl, as well as these associates, was by hydrothermal or pneumatolytic action, or more probably, by both, the minerals being deposited and the alteration accomplished by beryllium, boron, fluorine, and silica bearing waters and gases ascending along the fissures and reacting with the marble. Microscopic examination of slides of the altered rock does not show positive proof of hydrothermal alteration, although it is strongly suggested by an abundant development of mica and much chalcedonic quartz replacing the dolomite.

It seems further probable that the source of the beryllium and fluorine was magmatic, these elements being so minutely present in sediments and non-contact metamorphic rocks that their presence in any quantity is generally accepted as proof of the presence of magma.

This conception of origin is in harmony with the idea intimated by Pogue [5] in his discussion of the origin of the Columbian deposits, namely that the emeralds have a genetic connection with an igneous source.

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[5] Pogue, J. E., "The Emerald Deposits of Muzio, Columbia, South America," *Trans. Am. Inst. Min. Eng.*, Sept., 1916, pp. 799–822.

REVIEWS

Die Braunkohlen Deutschlands. By KURT PIETZSCH. 8vo. Pp. xii + 488, with 20 plates and 105 text figures. Borntraeger, Berlin, 1925. Price 27 gold marks.

The work here reviewed is one of a series of volumes that together will form a "Handbook of the Geology and Mineral Resources of Germany," edited by Dr. Erich Krenkel. Consequently it is not surprising that the emphasis is laid on the description of deposits rather than on the more theoretical aspects of coal formation.

The first part of the work discusses successively the physical and chemical properties of the German brown coals, the character of the seams, and the general genetic relations of the coals. This general part is thorough and adequate although no new light is thrown on the origin of coal. The author maintains that by far the greater number of the German brown-coal deposits are of autochthonous origin and his opinion is borne out by photographic illustrations of tree stumps in place in the open-cut workings. In one mine, these stumps occur at 7 horizons, showing that the accumulation of the coal-forming material was accompanied by progressive subsidence. Among the stumps have been identified those of trees belonging to the same genera as the bald cypress (*Taxodium*) of our southern swamps and the redwood and mammoth trees (*Sequoia*) of California.

The second and much the larger part of the volume is occupied with the description of individual coal fields. As a preliminary to this description, the coal-bearing area of Germany is divided into 4 main regions as follows:

1. The south German brown coal region of the South Bavarian-Swabian highland, Upper Pfalz and Upper Franconia, containing chiefly upper Oligocene and upper Miocene coals.
2. The west German brown coal region, with the great deposits of the Lower Rhine, containing chiefly lower Miocene coals.
3. The middle German brown coal region, between the Harz Mts., the Thuringian Forest and the Elbe, containing chiefly Eocene coals.
4. The east German brown coal region, lying east of the Elbe, especially in Lusatia but also in Brandenburg, Silesia and Posen, and in north and northeast Prussia. These coals are exclusively Miocene.

The individual fields within the 4 main regions are described in detail, with abundant illustrations. The great size of some of the open-pit workings is decidedly impressive and the floors of some, as shown in the excellent illustrations, are studded with large, closely spaced and vertical stumps.

The volume closes with a comprehensive bibliography of the more important publications on German brown coals, followed by a good index.

F. L. RANSOME.

Geological Maps. The Determination of Structural Detail. By ROBERT M. CHALMERS. Pp. 175, and 114 figures, with appendices on "Isostasy" and "Conventional Shading Methods." Oxford University Press, 1926. Price 12s. 6d.

This is a textbook intended to meet the requirements of students of mining and mine surveying. Its scope may be seen from the following list of the most important topics treated: The purposes of geological maps; the Ordnance Survey Dept. maps available; reading of plan detail; resection and orientation of a map in the field; representation of altitude by various methods; a discussion of stratified rocks, their age, the geological time table, rock systems, nature and form of outcrops, etc.; trend of outcrops; determination of dip, strike and thickness; folds; unconformities; faults; contemporaneous and intrusive igneous rocks; geosynclinals and geanticlines; and the making of structure sections. It is freely illustrated with diagrams which are explained in the text. The explanations are simple and direct so that there is no lack of clarity. This makes the book useful not only to students of mining but also to practical mining men who may have no formal knowledge of geology. The chapter on faults is the best and longest; it describes the effects of various kinds of faults on outcrops and explains in detail the determination of throw under various conditions. The subject is given a practical application by the use of examples involving coal beds, where "barren ground" is dependent on the heave of the faults. Both graphical and trigonometrical solutions of problems in dip and strike are given, with preference stated for the graphical method. Deductive rules are developed and printed in italics.

Definitions are given at the beginnings of many chapters, but in Chapter VII. on the Trend of Outcrops, the terms dip, strike, synclines, anticlines, faults and dykes are used, although not defined until subsequent chapters are reached. If it be argued that a knowledge of these simple terms is presupposed, then the later definitions appear unnecessary. For the sake of consistency and for the aid of the general reader

these explanations of terms might have been grouped into an early chapter.

Although the study of structures shown on maps naturally may raise questions regarding their origin, it may be questioned whether a discussion of that topic belongs in this book. At any rate the chapter on Geosynclinals and Geanticlines is out of place, and even with the aid of a statement of the theory of isostasy in the appendix it does not adequately treat the subject of structural geology. A further criticism applies to some of the chapter headings. The chapter on Variation of Dip deals not only with folds as might be expected but also with unconformities, overlap, outliers and inliers, and the chapter entitled the Study of Geological Maps deals entirely with the making of structure sections and the completion of outcrop maps from partial data.

A bibliography is appended as a guide to further study of structural geology and of geological mapping. Hence a large proportion of the references given are to standard textbooks on geology and to articles on structural geology, especially to articles on isostasy. A number of important American works are missing from the list. Footnotes are not used but a few references are cited in the text instead. References to maps outside of the text are few so that the book is remarkably self-contained.

Notwithstanding some editorial defects, the book is well suited for use as a textbook in the interpretation of geologic maps. Furthermore it is pedagogically sound in its explanations and procedure. Its clarity, its illustrations and its independence of additional maps are enough to commend it to the geological and mining public as well.

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Michipicoten Iron Ranges. By W. H. COLLINS, T. T. QUIRKE AND ELLIS THOMSON. Memoir 147, No. 127, Geological series, pp. 175, 15 text figures, 9 plates, 2 maps in pocket. Canada Department of Mines, Geological Survey.

This memoir is in two parts, a discussion of the iron deposits by Collins and Quirke, and one of the gold deposits in an adjoining area by Thomson. The iron ore and pyrite-bearing rocks are common to both areas and the two reports are logically combined in a single memoir. The outstanding feature of the memoir is the clear full statement of a theory of the origin of the iron formation which has been only briefly hinted in the preliminary reports by Collins, on the same district.

The Michipicoten area, near the northeast angle of Lake Superior has been the chief producer of iron ore in Ontario. It differs from most of the Lake Superior ranges in that the iron formation furnishes a large tonnage of siderite that can be roasted to ferric oxide, and a large tonnage of pyrite.

The chapter on the general character of the district is followed by one on the general geology before the discussion turns to the detailed consideration of the ores. The correlation used by the authors is a little confusing to those more familiar with the sequence studied by the U. S. Geological Survey geologists, south and west of Lake Superior. The problem arises out of the great conglomerate found in the Michipicoten district and known as the Dore series. Thick series of volcanic rocks lie both above and below the conglomerate and the iron formations are associated with the upper series,—probably with both. The authors throw all these formations into the Keewatin whereas the tendency south of the lake is to limit the Keewatin to that dominantly volcanic complex *below the oldest great conglomerate*. The Dore conglomerate may be, as suggested in one place in the report, only a local thing, but it seems to the reviewer that a more conclusive statement is needed before so great a conglomerate and any later series are placed in the Keewatin. The upper formations clearly differ from the Huronian rocks of Lake Huron, but since they are 200 miles away there is little reason to expect them to be the same petrographically.

The district has been the site of two granitic batholithic intrusions, one older than the Dore conglomerate and the other younger. This is the first place in Ontario where the evidence is clear of a granite older than both the Killarnean (Keweenawan) and the widespread "older granites," variously classified as "pre-Huronian," "Algomian," or "Laurentian." This confusion of nomenclature in the older granites may soon be cleared up by the definite announcement of a pre-Dore granite. It is to be hoped that it will, because south of the lake two granites older than the Keweenawan have long been recognized and the three age-terms above mentioned are not by any means equivalent. The Laurentian is pre-Huronian in the sense that it intrudes only Keewatin rocks and furnishes a basement for the oldest Huronian, but the Algomian as originally named and as used in the Rainy Lake region is supposed to be intruded in the midst of the Huronian—definitely younger than some sediments and older than the Animikian, much older than Keweenawan.

In their work on the iron formations the authors had the benefit of much commercial drilling and exploration not previously available. This in no way detracts from the credit which is due them for an accurate, ingenious and brilliant piece of structural mapping which furnishes the basis of an important suggestion as to the origin of the formation. They

found a new method for distinguishing the top and bottom of beds. At Goudreau, where the beds are but gently folded, they found a *uniform succession* in the iron formation. The authors are to be congratulated moreover on their success in checking this uniformity of stratigraphy by detailed mapping and interpretation. One can hardly doubt that they are right in concluding that all the iron formations at Michipicoten when fully developed consist from top to bottom of:

(1) A banded silica member, overlain sharply by a volcanic formation prevalently of basic composition.
(2) A pyrite member which grades downward into
(3) A carbonate (siderite) member which passes gradationally into an underlying volcanic formation usually of acid composition and usually pyroclastic.

The banded silica member makes up nearly all the small bodies and usually over three fourths of the large bodies of iron formation. Much of the silica is white, banded with gray or pink siderite, easily weathered to red; or less commonly with magnetite. The silica layers seem persistent on casual inspection but prove to be relatively short overlapping lenses. No mention is made of finding any organic remains in the silica, nor of a search for them. The sharp clean cut contact of the overlying green volcanics indicates that the volcanic is younger and not in any sense replaced by the silica.

The pyrite is most highly concentrated immediately beneath the banded silica member and in places alternates with it instead of having a single sharp contact. The gradation downward to carbonate is not regular; vaguely defined patches of carbonate are scattered through the pyrite.

All the iron ore deposits of Michipicoten are derived from the lowest member, the carbonate. This is poorly defined above and below, underlying the pyrite member and grading down usually in a zone of less than 10 feet into a tuff.

The iron ore is thus clearly a series of replacements of acid tuffs and it occurs at several horizons. Such evidence has not been so clearly found in any of the other Lake Superior ranges, but if searched for in the light of this clear case, it is possible that it may be found in several of the Keewatin districts. (No one thinks of these districts as closely analogous to the Animikian ranges, such as the Mesabi.) The authors proceed to outline the probable history in some detail.

The ores here as in other Keewatin districts, seem to be almost all of chemical origin. The constant association of the banded silica with the pyrite and siderite members, and the interbanding, indicate to the authors that all three members were formed at the same time and by the same chemical agent. The thoroughness of replacement suggests that the

waters were concentrated or hot, or both, the heat being indicated also by the associated volcanics, and by some pyrrhotite and a variety of ore metals. The banded silica probably was deposited by water flowing over a land surface of tuff, while the tuff below was being replaced by the same waters, rising from igneous sources and losing the solvent CO_2 and H_2S as a result of lowered pressure.

Aside from the evidences of replacement in the siderite masses much of this description resembles the processes suggested by Van Hise and Leith for other Keewatin iron ranges,—chemical deposition largely from igneous emanations, whether direct or indirect, early or late. The most notable difference is probably that Van Hise and Leith consider the ferrous state of the iron as opposed to origin on dry land, while at Michipicoten the features indicating dry land, though not individually conclusive, are so numerous as to have a cumulative effect and are convincing in spite of the siderite.

After this outline of the authors' careful work, the reviewer may be pardoned for mentioning what seems to be the weakest point in the discussion of the ore, viz., the conclusion that the three members were formed at the same time by the same agent. It is rather surprising at first thought to read that a surface deposit of silica was formed at the same time and by the same agent as a replacement deposit of pyrite and siderite. Siderite as a hydrothermal mineral is much more characteristic of moderate depths than of deposits near the surface. Pyrrhotite is even more deep-seated as a rule. Is it not likely that a surface deposit of silica over an acid tuff was formed with relatively little contemporaneous replacement? And that after deep burial under later rocks this silica served as an impermeable cap behind which igneous emanations were impounded in a way that resulted in a more thorough replacement than in rocks where the silica did not occur? This would seem to offer an explanation for two difficulties in the other theory. (1) The increasingly complete replacement toward the top of the carbonate-pyrite member would be expected if the silica acted as a barrier, but not if the solutions were freely escaping at the surface of the ground. (2) If the silica was deposited chiefly on the acid tuff, it would explain why later replacements were in that acid tuff, while a simultaneous replacement should find other rocks as favorable as the acid tuff. There is furthermore the point that in many cases, as in other districts, the banded silica member is not associated with any replacement. So many things probably happened to these old rocks that the evidence of a sequence of events may be almost lost. Even as the authors find ottrelite as phenocrysts in a porphyry, and carbonate as contemporaneous mineral in a greenstone, so they find replacement contemporaneous with silica deposition, on evidence that it is difficult to make convincing. Nevertheless the careful presentations of evidence and of

argument in the memoir are so impressive that most readers are inclined to believe the authors are correct even if there are weak points in the chain of evidence.

FRANK F. GROUT.

Practical Chemistry by Micro-Methods. By EGERTON CHARLES GREY. 124 pp. 16 figs. 1 plate. W. Heffer & Sons, Ltd., Cambridge, Eng., 1925. 4/6 net.

Since the student of ore minerals reaches out eagerly for any tool that promises to be of help to him in identifying minute grains on polished surfaces, the title of this book is more than ordinarily alluring. Let us hasten to add, then, that the methods it describes are designed to deal with solutions in what appears to be a veritably lavish and wholesale manner when viewed from the standpoint of the worker who is accustomed to content himself with the smallest drop of material dissolved from the surface of a minute grain. The author prescribes "micro" methods not because the supply of the available sample is limited but because by using small quantities of reagents one may save time, fuel and material—the motive is economy, surely a worthy cause but not provocative of the ingenious technique that a strictly microscopic sample sometimes demands.

The book is avowedly a manual for teaching to beginners the elements of chemistry and analysis, and it is excellently fitted to fulfill this mission. The ordinary blowpipe tests are described and the familiar qualitative procedure for separating the metals into groups is adapted for execution in Lilliputian test-tubes and retorts, the basic principles of chemistry being instilled the while by means of questions and experiments.

Unfortunately the most delicate and characteristic reactions, such as the nitroso-beta-naphthol test for cobalt, the glyoxime test for nickel and the cesium chloride test for antimony are not given, due, presumably, to the compactness and elementary nature of the book. However, one fine color-plate showing the appearance of precipitates in test-drops is alone sufficient to justify shelf-room for the volume and even the (dare we say) "mineragrapher" seasoned to the ingenuity of Chamot and Behrens-Kly may glean welcome suggestions from the descriptions of such devices as the micro-gas generator.

H. E. MCKINSTRY.

LABORATORY OF ECONOMIC GEOLOGY,
HARVARD UNIVERSITY.

Ice Ages, Recent and Ancient. By A. P. COLEMAN. Pp. xliii + 296. The MacMillan Company, New York, 1926.

Professor Coleman, whom the geologic world knows as an able protagonist of tillites, has recorded in book form the occurrences of possible,

probable, and proven glaciations throughout geologic history in all parts of the world. Much of the evidence Dr. Coleman has viewed in the field.

The volume is a notable contribution to geological literature as a summary of the work of its author and of others in the field of glacial geology. The factual material is not delivered in labored detail; indeed the presentation is almost too curtailed, for the subjects of the Pleistocene and pre-Pleistocene glaciations are covered in less than three hundred pages. The discussion is chronologically arranged and there is not undue emphasis on Pleistocene glaciation. The informally personal style does not lessen the value of the volume for purposes of scientific reference.

Bibliographies which accompany each chapter, an authors' index of over two hundred names testifying to Dr. Coleman's generosity of citation, and a general index facilitate the use of the volume as a reference work. Undoubtedly the author is annoyed by noting an occasional error, such as the incorrect spelling of an authority's name (Woodward for Woodworth, page 179; R. M. Campbell for M. R. Campbell, page 82; et cetera). The format, typography, and illustrative material, including diagrams evidently reproduced directly from the author's sketches, will commend themselves to the reader. The publishers have made a pardonable effort to popularize the book by clothing it in an attractive alpine jacket.

A. C. SWINNERTON.

Bibliography of the Geology of Oregon. Revised by DOROTHY E. DIXON. University of Oregon, Geol. Series No. 1, June, 1926. Pp. 125.

This is a revision of the bibliography issued in 1912, and comprises literature pertaining to paleontology as well as geology, also including a limited number of geography titles. The subject index with its cross references occupies nineteen pages, and is a valuable feature of the work.

SOCIETY OF ECONOMIC GEOLOGISTS

At the meeting of the Society of Economic Geologists, which is to be held at Madison, Wisconsin, Dec. 27–29, 1926, at the time of the session of the Geological Society of America, the following program will be presented.

W. H. Emmons: "The Zonal Arrangement of Metalliferous Lodes" (illustrated). 40 min.

S. J. Schofield: "Zonal Ore Deposits of the Coast Range Batholith."

George Berg (Berlin): "Zonal Distribution of Ore Deposits in Central Europe."

E. H. Davison (Camborne, Cornwall): "Recent Additions to the Evidence Confirming the Zonal Arrangement of Minerals in the Cornish Lodes." 10 min.

B. S. Butler: "Some Relations between Oxygen Minerals and Sulphur Minerals in Ore Deposits."

E. DeGolyer: "The Nash Salt Dome: a Study in Prospecting by Geophysical Methods."

F. F. Grout: "Alunitic Gold Ore from the Black Hills."

W. A. Nelson: "Bauxite Deposits in Virginia."

The Presidential address will be delivered on Monday morning at 9:30 o'clock. From 11 to 1 o'clock a joint session with the Geological Society of America will be held, at which the symposium on Zonal Arrangement of Metalliferous Deposits will be commenced. On Wednesday at 11:00 a.m., Mr. E. DeGolyer will present a paper on "Nash Salt Dome: a study in prospecting by geophysical methods" at a joint session of the Geological Society of America, the Society of Economic Geologists, and the American Association of Petroleum Geologists.

The following report has been submitted by Dr. Per Geijer.

Members of the Society of Economic Geologists present at the International Geological Congress in Madrid, to the number of 25, gathered for lunch on May 26th. After the luncheon, an informal meeting took place, the president, Mr. Bain, presiding. An animated discussion arose, chiefly concerning the possibilities of extending the Society's activities in countries outside North America. It was pointed out by several speakers that to non-American members the publications form the most important

side of the Society's work, and that the possibility of increasing the number of members, therefore, will largely depend upon the degree in which those joining will feel that they aid in the strengthening of the publication with which the Society coöperates, *i.e.*, ECONOMIC GEOLOGY. The distribution of reprints that has been going on for some years was commented upon as perhaps not economical; if members were to receive ECONOMIC GEOLOGY at a somewhat reduced price, the same results might perhaps be obtained with better economy for all.

It was also proposed by one member that the council may appoint one member in each country to act as a connecting link between the council and the members in that country, and to arrange for proposals of new members, etc.

The relations of oil geology to the other branches of economic geology were discussed by representatives of the oil geologists. From one side it was maintained that the journal ECONOMIC GEOLOGY ought to be devoted mainly to the geology of metalliferous deposits, and that oil geology ought to be treated there only as far as the basal principles were concerned, while other speakers pointed out that oil geology and general geology are very closely connected, and that both will profit from an intimate coöperation.

SCIENTIFIC NOTES AND NEWS

N. H. Darton is on furlough from the U. S. Geological Survey to carry on geological work in Venezuela for the Sinclair Oil Company.

H. C. Boydell has returned to the Massachusetts Institute of Technology after five months of work at Tyrone, New Mexico, for the Phelps Dodge Corporation.

T. A. Rickard has recently returned to New York from an extended European trip, during which he attended the International Geologic Congress at Madrid.

Sidney Paige, formerly of the U. S. Geological Survey, is now in Colombia, South America, for the Amerada Petroleum Corporation.

H. D. Miser has resigned as State Geologist of Tennessee to return to his former position with the U. S. Geological Survey.

Kirk Bryan, of the U. S. Geological Survey, has been appointed lecturer at Harvard, to teach physiography.

George E. Parish, who has been engaged in professional work for six months in Ontario, California and Colorado, has returned to New York City.

L. H. Freedman, geologist for the Marland Oil Company of Texas, has resigned his position and gone to Dallas to take charge of the geological and land department of the Goodman Drilling Company.

T. B. Nolan, of the U. S. Geological Survey, has completed his work at Gold Hill, Utah, and was in New Haven recently.

C. R. Thomas, formerly with the Amerada Petroleum Corporation, has opened an office as consulting geologist at 314 Clinton Building, Tulsa, Oklahoma.

The senior students in the School of Mines of the Alaska College, accompanied by Dean Ernest N. Patty, recently took a field trip in the Alaska Range.

George C. Matson, of the Schermerhorn Oil Company of Tulsa, recently found a laccolith of serpentine, while drilling near Lacoste, Medina County, Texas.

Charles P. Berkey recently delivered a lecture before the Geological Club at Yale University on the Gobi Desert of Mongolia.

H. D. Smith has again resumed his connection with the United Verde Mining Company, and is located at the New York office.

J. C. Hoyt, of the U. S. Geological Survey, is attending, as an official delegate, the International Navigation Congress at Cairo, Egypt.

Douglas G. H. Wright, chief geologist and exploration engineer for Dome Mines Limited, has been granted temporary leave of absence to assume the duties of professor in mining engineering at Queen's University, Kingston, Canada, during Professor S. N. Graham's absence in England on professional business.

Warner Newby, geologist of the Roxana Petroleum Corporation, was killed in an automobile accident near Tulsa, Oklahoma, on October 26th.

The U. S. Geological Survey has recently received word from its field men that the potash minerals sylvite, kainite, polyhalite and langbeinite have been found in Texas and New Mexico, and carnallite in Utah. Carnallite, sylvite and kainite are the minerals that furnish the basis of the German, Alsatian and Spanish industries.

The American Association of Petroleum Geologists held a midyear meeting at New York on November 15th, 16th and 17th. This first New York meeting proved a great success and was much appreciated by those who have difficulty in getting to the southern meeting places. Technical sessions were held Monday afternoon and evening, Tuesday morning, and Wednesday. Some 35 titles of papers were offered—and good papers they are—relating chiefly to Central and South America, Australasia and Asia. The Tuesday evening banquet in the Pennsylvania Hotel was unusual in two features—its excellent food at nominal cost, and no speeches. It didn't drag—skilled entertainers prevented that. The Tuesday evening symposium on the Theory of Continental Drift turned into a lively discussion. The address by W. A. J. M. Van der Gracht was vigorously opposed by Professor Charles Schuchert and was also discussed by C. R. Longwell and W. Bowie, and the discussion ended with a few not gentle remarks by Professor A. C. Lawson. There were contributed discussions by R. T. Chamberlin, J. W. Gregory, Bailey Willis, Alfred Wegener, G. A. F. Molengraff and others. The record should make an unusual volume.

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